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TECHNICAL COMMUNICATION No. 14

PROPAGATION BY CUTTINGS AND LAYERS. RECENT WORK AND ITS APPLICATION, WITH SPECIAL REFERENCE TO POME AND STONE FRUITS

by

R. J. GARNER

East Malling Research Station

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FOREWORD

Sixteen years ago a memorandum on the " Standardization of Horticultural Material, with Special Reference to Rootstocks " Hatton (1927), was produced by the writer at the request of the now defunct Empire Marketing Board. During the intervening years there has been great investigational activity throughout the world into the selection and standardization of most varieties of fruit and plantation crops—deciduous, citrus and tropical.

This present Technical Communication (No. 14) sets out to review the progress in the field of propagation with special reference to its application to deciduous fruit trees and it is the logical answer to that aspect of the Empire Marketing Board's questionnaire just as Technical Communications Nos. 7 and 13, Feilden and Garner (1936 and 1940), were the answer to the tropical problems.

The author has had a mass of unrelated literature to read and to evaluate for his purpose and he is to be congratulated in having so clearly interwoven into a coherent and chronological whole the main conclusions of some 250 papers by over 200 investigators, experimenting upon very diverse aspects of propagation all over the world. The complex reactions of the plant material and variety to an almost inexhaustible range of treatments in a series of very different environments is clearly emphasized and the conclusion drawn that there is unlikely to be any single road to success in rapid methods of vegetative propagation. However, when the threads of physiological and biochemical research on the subjects are gathered up and followed through by the pomologist, certain general principles are seen to be emerging for the guidance of the practical propagator in his choice of material, treatment and medium. There is growing up a logical explanation for his successes and failures. The author of Technical Communication No. 14 brings his readers down to earth by illustrating how he and his colleagues are trying to apply these principles in practice, chiefly for the rapid and economical multiplication of fruit tree rootstocks.

The moment for the appearance of this Communication is most opportune, when everyone is beginning to think of how to repair the devastation and neglect in their nurseries, orchards and plantations which have been the inevitable result of the world war.

In January, 1919, the writer appealed to the tree raisers of Europe to cope with a similar, if much smaller, catastrophe along orderly lines, but that appeal came too late and a great deal of rubbish was planted. To-day the methods of vegetative propagation are much more widely known and appreciated, and the more rapid and economical we can make them, the less likely are the orchards and plantations of the coming generation to be planted with unsatisfactory material. It takes several years to produce the best tree for its particular purpose—whether it be in the rubber plantations of the East or the orchards of the West.

Even in the countries which happily have so far not been scorched by war, there is a rapidly increasing demand for clonal rootstocks which will control tree size and cropping and meet particular requirements. Within the last 12 months letters have come from North America—both U.S.A. and Canada—stating that clonal rootstocks have now been sufficiently tested to convince many growers that they want the moderately dwarfed tree and that the amateur is crying out for the real dwarf. For the past few years considerable consignments of rootstocks have been shipped to North America, but both their investigators and nurserymen

say that the public want more. Europe, too, may soon be needing more than all there is available. Reports from Australia and New Zealand say that preliminary results with some of the new Merton Immune rootstocks compare favourably with the behaviour of trees on Northern Spy, and some of the more recent and still more vigorous East Malling Immunes are now required for trial in various localities. Thus tentative suggestions made under the aegis of the Empire Marketing Board 16 years ago have come home to roost with a vengeance and doubtless there is a similar potential demand for other horticultural and plantation material of known and standardized quality.

The Imperial Bureau has tried to make its contribution to the immediate situation as well as to long term research by inviting Mr. R. J. Garner, who is concentrating on problems of propagation at East Malling Research Station, to review the recent literature likely to throw light upon rapid and economical methods of vegetative reproduction. There is no doubt that the author's own " green fingers " will become even greener as a result of this review and it is sincerely hoped that the facts which he has so clearly assembled for the benefit of others will help materially in the sound and rapid renovation of the world's nurseries, orchards and plantations at no too distant a date.

R. G. Hatton.

INTRODUCTION

The art of vegetative propagation has apparently been practised from the dawn of human history. In the beginning division and separation was doubtless man's introduction to the art but this must soon have been followed by more complicated and ambitious designs. In 1672 *A Short and Sure Guide in the Practice of Raising and Ordering of Fruit-Trees* appeared under the name of Francis Drope of Oxford. Drope, writing of the great antiquity of layering, quotes Quintius Curtius, Book 6, wherein is described the experience of Alexander the Great who found the layering of briers and thorns to be " used by the Mardi, a neighbouring nation of Hyrcania, for the artificial fortifying of their country ". Virgil mentions the same in *Georgics* 2.

" Some trees require their boughs be set archwise
And make their own soil living nurseries."

Drope deals with propagation by suckers, stools, layers and marcots. Of this last he writes, " A better way to make a bough grow on the tree is by slicing off small pieces of the bark and hacking it a little in the place where the roots should issue forth, and then placing an old boot over the bough, so that the middle of it be the container of the place that is sliced, it being thus placed must be bound close at the bottom and filled with good earth afterwards in dry weather the earth should be watered, whereby the bough will send out roots into the boot." Essentially the same technique is used to-day, the chief difference being the substitution of an inner tube from a car wheel for the boot.

The obvious way of raising plants is by seed as, in general, it is easier than by cuttings or layers, but variation in seedlings has proved a major obstacle. Some measure of uniformity of seedlings has been obtained in America and elsewhere in recent years in characters such as winter hardiness, vigour and disease resistance.

The efficiency of plants propagated vegetatively is rarely questioned these days and the advantages of the practice have long been recognized. Stephen Switzer who wrote *The Practical Fruit Gardener* in 1724 remarks that " Plum Stocks will take by Arenation or Laying, which by Experience is found to be a much quicker and as successful a Way as from the Stones ".

In an orderly world the unpredictable variability of seedling plants will not much longer be tolerated. The use of clonal scion varieties is recognized as essential and recent work with fruit tree rootstocks and with " strains " of small fruits and other subjects grown on their own roots has made clear the advantage to be gained by the use of selected varieties propagated vegetatively. In years to come it seems likely that we shall insist upon having all our woody and many of our herbaceous plants vegetatively propagated, including perhaps forest trees and hedge plants.

Determination to persist in vegetative propagation has brought into prominence the many problems still awaiting solution and there is a keen desire to increase our knowledge of the subject. Investigators are widely scattered throughout the world and are working with many different kinds of plant, but it may well be that advances along one line may, if generally known, assist others to elucidate their own particular problems. It has therefore seemed opportune to bring together the results of recent research which have proved useful to

propagators, to illustrate their exploitation in practice and to suggest possible lines for further investigation.

Relevant literature appears to be almost inexhaustible and it has only been possible to make a selection of those articles which seem to have a direct bearing upon the propagator's technique. No mention is possible in this brief review of much of the literature which has necessarily been examined. It is, however, more than likely that despite all efforts certain important contributions have remained unnoticed. Details of relevant information not included and comments on other points raised will be most welcome.

The date of appearance of the matter has not been allowed to dictate the order of discussion which actually follows the order in which the material is handled by the propagator. Thus, in dealing with cuttings, the order observed is (*a*) Source or internal condition when collected, (*b*) Treatment between collecting and planting, (*c*) Planting and subsequent treatment.

In dealing with methods other than by cuttings such as layering and the like it has been found convenient to deal with each under its own heading.

Following the review, the chief methods in use at East Malling for deciduous fruits are briefly described and, finally, tentative suggestions are made of lines of enquiry which, it is thought, might lead to technical improvements in methods of vegetative propagation.

REVIEW OF THE LITERATURE

VARIATION OF PLANTS IN EASE OF PROPAGATION

Plants vary widely in their response to vegetative propagation. Some may be cut in pieces, each piece being treated as a separate entity and surviving and growing satisfactorily. Others even with the utmost care in the nursery only regenerate slowly, if at all. Not only do species behave differently but varieties often respond very differently to particular treatments. Thus mere botanical relationship is no reliable guide to the propagator.

Knight and others (1927) state that not only is it necessary to use different propagation methods for different species and genera, but even varieties closely similar frequently respond quite differently to the same treatment. Consequently, the propagation problem resolves itself at first into a series of empirical trials of every variety which may be required. Elucidation of the principles involved is of considerable value in a general way, but application of these principles to each individual variety is handicapped by this wide variation of inherent potentialities.

PROPAGATION BY CUTTINGS

A. SOURCE OF MATERIAL

1. AGE OF PARENT PLANT

Yerkes (1923 and 1926) found that one-year-old roots of apple when used as root cuttings gave better results than older roots. This bears out the practical propagator's conviction that root cuttings collected from maiden trees give better results than those from older trees. Working with hardwood cuttings of apple, pear, cherry and other subjects, including evergreens, Gardner (1929) showed that rooting decreased with increasing age of the plant from seed. Cuttings made from the tips of one-year-old seedlings rooted readily, whereas, if the seedlings were two years old, even though the one-year wood was used, the percentage rooting dropped very markedly. Similar results were obtained by Wierszyllowski (1937) with pears. Gardner (1929) found that in plants cut nearly to the ground after the first year's growth, the resulting growth could then be rooted with more success than the one-year wood of two-year plants not cut back. Precautions were taken to avoid the inclusion of stem which might have become partially blanched near soil level. Gardner suggested that the destruction of a young plant to form one or two cuttings was uneconomical but pointed out that it might be possible to obtain similar material in larger, older plants by suitable manipulation. Gardner, quoted by Auchter (1930), found more leaves per unit on young apple seedlings than on older plants. Two-year apple seedlings cut to the ground had nineteen square centimetres of leaf to each gramme of woody portion (fresh weight of tops and root) as against fifteen square centimetres in unpruned plants of the same age.

Vekhov and Iljin (1934) table results with 600 varieties of trees and shrubs. They state that the age of the plant from which the cuttings are taken exerts considerable influence on the formation of callus and roots. Shoots from young plants root better than those from older and rejuvenation, presumably by severe pruning, with the formation of abundant shoots from the stump, considerably augments the rooting capacity of the material.

Cheesman and Spencer (1936b) found that leafy stem cuttings from young, non-bearing cacao plants rooted better than those from more mature trees.

Thimann and Delisle (1939) investigating the vegetative propagation of shy rooting plants confirm that the ease with which roots are formed on one-year wood falls off with increasing age of the tree, whether the cutting is treated with growth substance (*see* page 19) or not. In some conifers, notably *Tsuga canadensis* and *Picea pungens*, cuttings from old trees rooted well if treated with growth substance but failed to root without this treatment.

Stoutemyer (1937) recognized two distinct growth phases in the apple and found these phases to be closely related to the ease of regeneration of roots on stems. Thus cuttings in the juvenile phase rooted readily, but those in the mature phase rooted only very little and very slowly. The juvenile phase was recognized by thinness of leaf and little pubescence. In some species of apple the shape of the leaf changed with maturity so that oval leaves were borne at the base of shoots and lobed leaves, typical of maturity, higher up the shoot. The investigations were continued for some six years and included a study of the origin of the shoots used as cuttings. It was found that so-called " watersprouts " in mature apple trees are not truly adventitious as are the shoots which arise on roots. Watersprouts were found to arise from latent buds rather than from adventitious buds. The only adventitious buds produced on stems were found on sphaeroplasts. Roots placed under favourable conditions of temperature and moisture produced abundant adventitious shoots which rooted readily when used as cuttings. The best results were obtained by placing the roots in sphagnum moss and the pictures appear to indicate that considerable etiolation of the new stems occurred. Knight and Witt (1927) found that shoots etiolated at their base, when used as softwood cuttings, rooted not only better, but entirely differently from non-etiolated cuttings. The rooting reported by Stoutemyer is not described in detail. Stoutemyer also used leaf-bud cuttings and obtained over 90% success using young seedling material and about 70% with leaf-bud cuttings from adventitious shoots on roots. Only one or two per cent. of many hundred leaf-bud cuttings rooted when taken from shoots in the mature growth phase.

The use of surplus adventitious shoots produced on root cuttings is a tempting proposition, but with some subjects there is a risk of propagating variants. Jørgensen (1928) used shoots from decapitated tomato plants in order to obtain heteroploids. On the cut surface the callus tissue gave rise to a cluster of shoots which were all used as cuttings. This procedure was repeated up to ten times or more before the stock plant became too old. Besides the production of heteroploids, chimaeras were occasionally forthcoming. Mendiola (1933) discusses plant improvements based on mutilation and the use of small cuttings, such as pieces of root.

Frischenschlager (1938) working with apple seedlings and established scion varieties, found that root cuttings from new seedlings rooted with ease but he had great difficulty in rooting older scion varieties.

Knight and others (1927) noted that success is often obtained by planting old stems, but the material most easily obtained is in the form of current year's shoots and very often these come from hard pruned trees or stools and layers. This vigorous material is least likely to be successful, but is the most readily available. Moreover, if successfully propagated, it gives the most satisfactory type of plant for further nursery work.

2. CONDITION OF PARENT PLANT

Starring (1924) found that a high carbohydrate content of softwood cuttings, with low soluble nitrogen, favoured rooting. He stated that firmness of stems may often be taken as an index of their fitness for cuttings in so far as the carbohydrate content is concerned. Stems low in carbohydrate are soft and flexible in contrast to those high in carbohydrates which are firm and stiff. This condition is not to be confused with firmness caused by thickening and lignification of cell walls. Schrader (1925) went somewhat further and stated that, if high carbohydrate content is accompanied by almost complete lack of soluble nitrogen, rooting is less and shoot growth practically inhibited. Thus a cutting from non-vegetative material high in carbohydrates will regenerate in varying manner and degree depending upon the supply of soluble nitrogen. Schrader also found that vegetative material, high in soluble nitrogen, produces shoots and not roots, or, if carbohydrates are lacking, no regeneration occurs and the cutting decays.

Apparently the first to classify cuttings according to their internal condition, judged by external manifestations, was Knight (1926). He recognized three types of stem cutting on each mother plant in June : (1) leader tips in active growth, (2) laterals in active growth, and (3) laterals with the terminal bud formed. He found that the firm cutting which had ceased growth was much superior to actively growing shoots and suggested this was probably due to higher carbohydrate content. He noted that propagators preferred cuttings from pot plants

where the root run is restricted and cannot keep pace with the shoot growth. Witt (1928) obtained softwood cuttings of walnut from potted plants brought into a warm greenhouse in February. As soon as the shoots were four inches long they were taken for cuttings. Passecker (1940) also found summer cuttings from potted plants superior to plants collected later from outdoor grown unpotted plants. Read (1930) found that any condition favouring a high carbohydrate/nitrogen ratio favoured rooting, and she pointed out that full light on abundant leaf area favours this ratio. On the other hand Vekhov and Iljin (1934), working in Russia, obtained increased rooting in species of *Cotinus*, *Acer* and *Quercus* with artificially shortened day.

Larina (1939) obtained cuttings with short internodes by growing the parent plants under short day conditions. Plants grown under long day conditions had larger leaves and higher oil content but were less suitable for this method of propagation.

Mitchell (1936) found that cuttings rooted better and decayed less when the parent had been exposed to arc light compared with plants grown in winter light.

Feilden and Garner (1940) discussing experiments with *Coffea* spp. state that the best type of soft wood cuttings are obtained from plants grown in full light. They have short internodes and though they may not callus so quickly as those from shaded plants they show less tendency to rot.

Attempts have been made to improve the quality of material for cuttings by wiring and ringing shoots whilst still attached to the parent plant. Bobilioff (1934) obtained increased rooting in *Hevea brasiliensis* by binding shoots with wire three weeks before taking the cutting with its base immediately below the place wired. A swelling occurred immediately above the constriction and it is suggested that the extra stored food in the cutting assisted regeneration. Vierheller (1923) ringed shoots of apple during the summer in an attempt to increase their food storage, but this material, used as cuttings, was in no way superior to unringed shoots.

Hunter (1932a) using citrus found that it was necessary to ring neither too short nor too long a time before taking the cutting. In Rangpur lime the optimum was fifteen days. A ring of bark is removed and left uncovered. When the cutting is made, care is taken not to injure the bark in any way and the severance is made in the middle of the ring, cutting through the bare ring only.

Thakurta and Dutt (1941) ringed shoots on young mango trees and smeared the ring with lanolin containing 3% indole acetic acid. After twenty-four hours the shoots were severed at the lower edge of the ring and planted slantwise as cuttings. Thus treated the cuttings rooted ; meanwhile no rooting occurred in the untreated cuttings. Similar treatment with naphthalene acetic acid was ineffective.

Pridham (1942) stored parent pot plants of *Ligustrum ovalifolium* at 40° F. with daily illumination of ten hours for six weeks. Cuttings taken at the end of this period callussed less and rooted more quickly, though less in amount, than cuttings from plants not cold stored. Still more important, bud break and top growth were early and abundant. Pridham tried various nitrogenous compounds as stimulants with and without growth controlling hormones and came to the conclusion that rooting of cuttings and subsequent growth of the young plant depend primarily upon the maturity and treatment of the parent. He considered the stimulants, alone or in combination, to be of secondary importance.

Carlson (1929) finding that young shoots of the Dorothy Perkins rose rooted quickly in humid air, whereas those of American Pillar failed to do so, made detailed examinations of the starch content of the shoots of each. She found that, at the time of rooting, Dorothy Perkins had considerable starch remaining in the rooting shoots while during a similar period the reserve starch of American Pillar was depleted. Carlson, therefore, suggested that the rooting of these subjects was related to the stored food within the cutting.

Portères (1939), working with coffee, rooted cuttings best following a dry season and this he attributed to the greater amount of stored food within the cutting. At first sight the findings of Brandon (1939), who worked with rose, appear to be contrary seeing that she found the starch content of cutting to be unrelated to rooting. But, bearing in mind the findings of Schrader (1925) (*see* page 12) and others, that presence or absence of soluble nitrogenous compounds has an over-riding influence on regeneration, it may be that this factor operated in the case cited by Brandon in which the possible effect of nitrogen is not mentioned.

Jackson (1939) found that even though a batch of softwood cuttings of *Coffea* were planted at one time in a uniform medium in a single frame they started to root in ones and twos over a period of a year or more.

That the nutrition of the cutting material is of very great importance is recognized by many and this is shown by the attempts to induce a high carbohydrate/nitrogen ratio in stock plants by ringing, notching and constriction, by root restriction and the provision of extra illumination. The importance of carbohydrate content has been so stressed that other conditions have frequently been neglected, even though it is clear that the alteration of one factor will almost certainly affect the action of the others. References to carbohydrate/nitrogen studies have already been mentioned and attention drawn to the effect of pot culture of stock plants used as a source of cuttings. Sinha and Vyvyan (1943) found that cuttings of the plum Malling Myrobalan B rooted better when taken from an established hedge than from either vigorous layer beds or newly established, widely spaced plants. The rooting was of the following order. Hedge cuttings, 80%; layer cuttings, 69%; plants lined out and budded, 47%; one-year rooted cuttings 28%. An established hedge in some ways provides similar root conditions to those obtaining with pot-bound plants, but not entirely so. In pots the root run is clearly limited by the size of the pot. In the hedge the root run is in competition with other roots but not restricted in the amount of soil available for exploitation. Thus it is possible that the root/shoot ratio of hedge plants is higher than either pot plants or widely spaced plants; in poorer soils root shoot ratio is higher, Rogers and Vyvyan (1934). Eaton (1941) working with maize and tomato, divided roots of the same plant between culture solutions of differing osmotic pressures and found that more roots developed in the dilute solution. Pearse (1943), working with vine cuttings from plants grown with their roots in different solutions, found that the subsequent rooting of the cutting was greatest when the stock plant was starved of minerals. This starved material responded more favourably to stimulation with hormones and to treatment with soluble nitrogen. Pearse writes: "From the practical viewpoint these results seem to indicate that material cultivated especially for propagation by cuttings needs special nutritional treatment, and should presumably be grown on a poor soil low in nitrogen; cuttings obtained from such material should then be treated with root forming substances and transferred to beds containing a readily available supply of soluble nitrogen." He points out that stock plants having an abundant root system retain this property in the cuttings taken from them, which in turn exhibit it by regenerating a great number of quickly growing roots.

In root cuttings Hilkenbäumer (1940) found that the performance of root cuttings, obtained from worked trees, was influenced by the particular scion variety.

Parent plants are sometimes set aside solely for the production of suitable material for vegetative propagation. Nurserymen retain stock plants from which cuttings are taken periodically or branches layered in the surrounding soil or inarched into rootstocks planted temporarily nearby. Large shrubs and hedges are sources of abundant cutting material. The treatment of young quinine plants (*Cinchona* spp.) is described by Molodozhikov and others (1938). The parent plant is cut back to four inches above ground level. Resulting shoots are bent over in an arc with their tips pegged to the ground. The tension causes numerous dormant buds to grow. These are used as cuttings when they have made three nodes; care is taken to leave one node on the shoot as a starting point for fresh growth. A three-year-old bush so treated will produce 60-80 cuttings as against its usual 7-10.

3. FEATURES OR CHARACTERS DESIRABLE OR UNDESIRABLE IN PARENT PLANT

(*a*) Burr knots

Some woody plants exhibit collections of incipient roots known as "Burr knots" on their stems. Wolf (1913) working with figs (*Ficus carica*) planted twigs having "numerous cylindrical or conical outgrowths" and found that these protuberances quickly grew and became roots. Hatton (1917) noted this phenomena when selecting apple rootstocks. Swingle (1925) used burr-knot wood in the propagation of apple varieties by cuttings. These rooted readily but smooth, non-burred shoots only rarely. Swingle states that time, media, temperature, light, humidity, etc., all probably play a part in determining the final result, but by far the most

important condition is the presence of definite root primordia in the cutting when collected. Hatton, Wormald and Witt (1926) showed a close correlation between knotting and rooting. They point out that many plants never show aerial root knots yet their stems root readily. On the other hand, prolific knotting is a sure sign of easy rooting.

Burr knots are usually grouped at the junction of branches, and in the region of nodes, and cuttings which include such areas towards their base root exceptionally readily.

(*b*) **Root initials**

Van der Lek (1930), who has studied the anatomy of stems in relation to rooting over many years, finds that the rooting potentialities of stem cuttings can be determined by the presence or absence of root germs (root initials) observed in the microscopical structure. Van der Lek quotes Graevenitz (reference not available) who in a thesis dated 1913 detailed work with one-year-old branches of ready rooting subjects. Graevenitz found that all roots arose from pre-formed initials lying between the wood and the bark, and always where an unusually wide primary wood ray met the cambium. She concluded that the first condition for rooting was the presence of root initials. Van der Lek found a decrease in number of root initials from the base to the tip of the branch.

(*c*) **Flowers**

Bayley Balfour (1913) reported that, in leaf propagation of begonia, leaves near the flowering region, if used as cuttings, will give rise to plants that flower earlier than can be achieved otherwise, unless the cutting consist of the whole flowering shoot. Generally the presence of flowers on a cutting is detrimental. Wóycicki (1938) working with cuttings of dahlia, geranium, carnation, chrysanthemum, hydrangea and fuchsia found that the presence of flower buds was unfavourable to rooting. O'Rourke (1942) also found that flower buds on hardwood cuttings were associated with lack of rooting in the blueberry (*Vaccinium atrococcum*). Results indicated that it is not the presence of the flower buds that depresses rooting but rather the conditions that lead to the formation of flower buds. The labour involved in removing blossom buds was not compensated by increased rooting, hence the use of flowering wood as cuttings seems inadvisable. Tukey and Brase (1934) obtained over 90% rooting of black and purple raspberry leaf-bud cuttings, even though the leaf-bud cuttings were taken from laterals on the previous year's growth, which being fruit buds, made no new shoot growth but merely developed into flowers.

(*d*) **Leaves**

Calma and Richey (1930) working with coleus found that rooting was governed by the leaf area of the cutting. Cuttings with the greatest leaf area produced the largest amount of roots. Size of cutting is clearly bound up with the number of leaves. Esper and Roof (1931) also found that root development is proportionate to leaf area.

With hardwood cuttings of plum rootstocks Vyvyan (1943) found that leafless cuttings generally failed to root as well as those which retained their leaves for a few weeks after planting. He tested the effect of one, two and three leaves upon subsequent rooting and showed that though cuttings with three leaves were superior to leafless cuttings there was no significant difference between three and two or between one leaf and none. It seems clear that the good effect of leaves is proportional to the quantity adhering.

In leaf-bud cuttings the stem portion is very small and the leaf area relatively very large. Success appears to be mainly dependent on the presence of a large healthy leaf, and Garner and Hammond (1939) suggest that the portion of stem should be very small and not include even a small portion of pith. Leaf-bud cuttings are used on a fairly large scale for the propagation of blackberries and hybrid berries, which naturally root by tip-layering, and the technique has been extended to many other subjects. Stoutemyer (1937) obtained 69% success with apple leaf-bud cuttings and Watkins (1940a) found it a ready means of propagating fifteen genera of tropical and sub-tropical ornamental shrubs.

4. CHOICE OF MATERIAL FROM PARENT PLANT SELECTED

(*a*) Laterals or terminals

It is reported from Tanganyika (1937) that the rooting propensity of coffee cuttings apparently varies from tree to tree and between different parts of the same tree.

Grace (1939a) and Farrar and Grace (1942) working with Norway Spruce found that cuttings taken from the lower part of the tree rooted better than those from the upper part and that laterals were consistently superior to terminals. This bears out Knight (1926) who, using softwood cuttings of *Pyrus* and *Prunus*, found that non-elongating laterals rooted better than either laterals or terminals in active growth. Somewhat to the contrary Pyke (1932) found that in cocoa chupons (upright vigorous shoots) rooted better than fans (horizontal growing shoots).

Graham and Stewart (1930) and Graham (1934) pointed out that in trees with horizontal branches very diverse plants result, depending on whether an orthotropic or plagiotropic cutting is inserted. Where plants exhibit horizontal branching with marked dorsiventrality, as occurs in conifers, gardenia, napoleona, branch cuttings develop into dorsiventral plants to which varietal names of *nana* or *pendula* are given. In *Gardenia amoena* side branches yield floriferous plants in two or three seasons.

(*b*) Etiolated shoots

Knight and Witt (1927) had great success with cuttings which had been etiolated at their base whilst on the parent plant. Such material was produced in the normal layering process (*see* page 42). Gardner (1937) obtained similar results in apples by growing shoots inside black paper tubes and using this etiolated portion as the base of the cutting.

(*c*) Region of shoot preferred

Tukey and Green (1934) examined rose shoots and found a gradient of increasing moisture, ash and total nitrogen from base to tip and a gradient of decreasing starch content. They urged the importance of keeping cuttings in numerical order in trials so that effects due to portion of shoot used may be more readily traced to their origin. Van der Lek (1930) found more root initials in the bases of shoots than in the tips (*see* page 15). Podluzhnii (1940) propagating the olive, found that cuttings from the lower third of the shoots rooted best, those from the middle next best, and those from the terminal section scarcely at all. Tukey and Brase (1936) in discussing the yield of rooted shoots from apple and quince stoolbeds suggest that output may be augmented by striking the unwanted tips from plants longer than is necessary and that a good percentage of them may be expected to root. It is not suggested that this provides ideal cutting material but it makes use of material which would otherwise be destroyed. Vyvyan (1943) has demonstrated that the portion of shoot used has a direct bearing on the rooting and, moreover, that rooting both in the upper and lower regions of a shoot is affected by etiolation of a small area at the base of the whole shoot. Thus in the Common Mussel plum rootstock the lower portion of shoots not etiolated at their base rooted 33% and the upper portion 41%, whilst the lower cutting from basally etiolated shoots rooted 49% and the upper portion 9%. The total number of successful cuttings from a given number of shoots, whether the bases had been etiolated or not, was similar but there was a distinct advantage in using cuttings etiolated at their base. Vyvyan writes: "Etiolation of the base caused a great increase in the (rooting) capacity of the basal cutting but a corresponding decrease in that of the middle (upper) cutting. This suggests that some substance, possibly a growth substance, is present in the shoots and must reach a certain minimum concentration for rooting to occur. In unetiolated shoots the substance would appear to be uniformly distributed and to reach this minimal value in a certain proportion of the shoots. Etiolation of the base would appear to concentrate the substance in the basal portion at the expense of the upper portion so that the minimal value would be reached more frequently in the base and more rarely higher up."

(*d*) Heeled or non-heeled cuttings

From time immemorial heeled cuttings have been recommended as giving better results than straight or heelless cuttings. This recommendation needs qualification. In softwood

or summer cuttings the presence of a heel is usually a disadvantage, increasing the time taken to form roots and reducing the number of cuttings rooted. Hitchcock and Zimmerman (1932) using greenwood material compared the rooting of four types of base to the cutting (1) a mallet of previous season's wood, (2) a heel of previous season's wood, (3) cut at the base of the current season's growth, (4) cut from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. above the base of the current season's growth. Although species responded very differently the mallet type (1) was generally poor and those cut at the base (3) usually good. They point out that it is also important to learn the type of cutting which will give maximum rooting at any particular time. Wóycicki (1938) found that heelless cuttings of dahlia and pelargonium root quicker than heeled. Contrary to softwood cuttings heeled hardwood cuttings have generally given the best results. Tukey and Brase (1931) found that heeled hardwood cuttings of quince rooted far better than non-heeled. Insistence on the use of heeled cuttings would seriously curtail the amount of cutting material obtainable.

(*e*) **Size of cutting**

(i) STEM CUTTINGS. Hatton (1919) and (1921) describes the successful use of heelless, hardwood cuttings six to eight inches in length. Knight and others (1927) used hardwood cuttings eight to ten inches in length.

Hunter (1932b) describes the use of hardwood citrus cuttings 12 in. long and says that they suffer from a serious defect which is that the plant produced is not suitable as a stock for budding. The plant consists of a hard stem, the bark of which does not slip easily whilst the numerous shoots produced at the top of the cutting are too thin and sappy to bud.

Garner (1943) reports the use of cuttings over 12 in. in length and suggests that the length of the cutting is somewhat determined by the use to be made of the resulting plant. Short cuttings are not readily anchored in soil and are more easily disturbed by cultivators and lifted by frost than long cuttings. Deeply planted long cuttings have their bases in a medium whose temperature and moisture content fluctuates relatively little.

Very large cuttings are sometimes recommended. Posts of undried willow (*Salix* spp.) driven into the ground often take root and grow into trees. The use of branches of mulberry (*Morus* spp.) some three or four feet in length, as cuttings in moist situations is recommended in numerous textbooks. Saleeby (1927) and Opsomer (1932), discussing the propagation of kapok, say that cuttings of fairly large dimensions are preferable. Cuttings from 18 in. to over 7 ft. in length and up to $2\frac{1}{2}$ in. in diameter set deeply in the ground, are used with success. The wood should be at least a year old and well ripened. When such plants are transplanted they are cut to 3 ft.

Knight and others (1927) when raising rootstocks for deciduous fruits preferred softwood cuttings 3 in. long and often made use of cuttings only 2 in. in length.

Hitchcock and Zimmerman (1942) recommend the use of young apple shoots when they reach a length of 4 to 7 in., i.e. during May in New York. Such material, treated with 8 mg./gm. powder preparation of indolebutyric acid, planted in sand in a shaded greenhouse rooted well (*see* page 20).

(ii) ROOT CUTTINGS. The size of root cuttings has received considerable attention. Yerkes (1926) stated that small portions of root $1\frac{1}{2}$ in. long and as thin as $\frac{3}{8}$ in. gave as good results as larger pieces, provided they were under controlled conditions under glass. In the open ground very small cuttings are injured by adverse conditions. Hatton (1921), Cummings (1933), Hoblyn and Palmer (1934) and Hilkenbäumer (1940) preferred large cuttings and agree that root cuttings should be over $\frac{1}{4}$ in. thick and 5 to 6 in. long.

5. TIME AT WHICH CUTTINGS SHOULD BE TAKEN

This should, apparently, be related to the condition of the plant and to the climate rather than to the calendar. In England, with its temperate climate hardwood cuttings are cut and planted in September-October whereas in parts of North America they are collected in the autumn and planted in the spring. This involves storage conditions which have received attention from various workers (*see* page 24 under the heading Temperature, Light and

Moisture). Tukey and Brase (1935), working in America, found that cuttings taken in autumn and stored until spring rooted better than cuttings taken and planted in spring.

Knight and others (1927) describe the planting of hardwood cuttings in October in England. " Callusing occurs during the first two months after planting and root production usually begins in spring, the time depending upon variety and conditions."

Vaidya (1938) working with the apple rootstocks Malling II, V, VII and IX found the seasonal cycle of ash constituents to be one month earlier in IX than in the others. Rao and Berry (1940) reported that IX accumulated starch and ceased growth earlier than XIII. Carlson (1929) working with rose cuttings found rooting to be correlated with starch content in the cutting. Though Brandon (1939) did not agree with this, it is generally agreed that "well ripened " hardwood cuttings, presumably having high storage content, make the most reliable cuttings. Thus they are, more often than not, collected at the end of the growing season or before growth begins in the spring.

Graham (1934) lists some 200 plants with the optimum time of taking cuttings at Edinburgh. He states that the time at which the cuttings should be taken can only be determined by experiment, a general guide is to take cuttings when the season's growth is completed. The end of the season's growth does not refer to any division of the year but *is peculiar to each plant and each season.*

Van der Lek (1934) states that in dormant cuttings the dormant buds check root development. This check diminishes as the dormant period nears its end. Knight (1926) pointed out that callus formation and root production are two distinct processes and callus is not necessarily indicative of root formation.

The time of planting softwood cuttings has been studied by many. Knight and Witt (1927) found that early cuttings rooted best provided the leaves were fully expanded and the terminal bud had formed. By early planting a longer season is available for the development of roots. The sunlight of June may be a contributory factor and Tincker (1938) suggests that root forming hormone production is related to the effects of the photoperiod. Vekhov and Iljin (1934) working with six hundred varieties of trees and shrubs had better results with June than with July cuttings.

Hatton (1921) collected root cuttings during the winter and stored them in sand until March when they were planted in the cutting beds. Such is the general horticultural practice in England, being governed by the tree lifting programme. When trees are lifted from the nursery, roots are cut off and made into cuttings. Kreyer (1938) found this, the normal lifting time, to be a convenient time for collecting roots of cinchona in the U.S.S.R. Stoutemyer (1937) states : " Root cuttings (apple) can be made at any time of the year with the assurance that they will produce adventitious buds very quickly." " Shoot production was definitely smaller if the cuttings were taken during the short season of very active growth which culminates in June."

SUMMARY

1. Young plants are a better source of cuttings than older plants and there is evidence that material in the juvenile phase regenerates readily. Suitable treatment of older parent plants results in the production of material which behaves similarly.

2. Cuttings should be rich in stored food (carbohydrates). This condition can be brought about by manipulation of the parent plant and of the environment.

3. The presence of root initials or burr-knots is followed by quick rooting. Leaves on stem cuttings are a definite advantage, their absence may preclude rooting. Flowers on cuttings are usually accompanied by poor rooting.

4. Lateral shoots are almost always better than terminals. In shoots long enough to provide a number of cuttings the basal cuttings root best. In hardwood cuttings rooting is further improved by the presence of a heel.

The size of cuttings affects their reaction to local conditions but is often dictated by the material available and the use to be made of the resulting plant.

5. The time of taking cuttings should be governed by the condition of the material rather than by the calendar.

B. HANDLING OF CUTTINGS PRIOR TO PLANTING

4. TREATMENT WITH EXTERNAL SUBSTANCES

(*a*) Synthetic growth substances

The practice of treating cuttings with external substances before planting them has been largely confined, in recent years, to the use of certain synthetic compounds valuable for their property of promoting root growth. The method derives from the work of the plant physiologist who has shown that growth in plants is controlled by chemical substances which recall the hormones of the animal organism. The main group of these phytohormones consists of substances which cause cell elongation, and which can be detected by their effect in causing the *Avena* coleoptile to bend. Three compounds of this group, the auxins, have been isolated, and the fact that one of them was found to be a well-known organic substance, β-indolyl*-acetic acid, capable of laboratory synthesis, has made possible its widespread investigation as an agent for promoting rooting in cuttings. For a general account of phytohormones the reader is referred to the monographs of Boysen-Jensen (1936) and Went and Thimann (1937), while Pearse (1939b) has exhaustively reviewed the subject in relation to its practical applications in vegetative propagation.

Many synthetic growth substances have since been shown to aid the rooting of cuttings, but the two now in common use are β-indolyl*-butyric acid, and α-naphthalene-acetic acid, either in this form or as salts. Thus Grace (1937) found that β-naphthalene-acetic acid and its potassium salt caused increased growth of roots and tops, the salt being slightly more effective than the acid; while Hitchcock and Zimmerman (1939) report higher activity of the salt in the rooting of cuttings of *Hibiscus syriacus* and other plants and suggest that this indicates solubility and penetration are important factors regardless of how the root-inducing substance is applied.

(i) Methods of application. Of the various ways in which growth substances are applied those proving the most practicable are the solution method and the dust method. Injection, soaking, the insertion of impregnated toothpicks, spraying with solutions, smearing with lanolin in which the substances are dissolved and continuous absorption of solutions are other methods which have been tried with varying success.

The solution method. Pearse (1939b) described the preparation of solutions of indolyl-acetic acid, indolyl-butyric acid or α-naphthalene-acetic acid as follows: "A 1% stock solution is prepared by dissolving 1 gram of the acid in 50 c.c. of 95% alcohol and adding a further 50 c.c. of tap water. Each cubic centimetre of this solution contains 10 mg. of the substance. The stock solutions keep well if stored in a cool dark place until required. From this stock solution those of the requisite strength for treatment of the cuttings can easily be prepared by dilution." These stock solutions should be kept in stoppered bottles in a cool place, opaque glass or stone-ware bottles being preferable. Should the activity of the solution be in question it may be tested as described by Hitchcock and Zimmerman (1938). Newly expanded tomato leaves 6 in. to 10 in. long are severed from the parent at the base of the petiole. Some are immersed in the diluted stock solution for twenty-four hours at a depth of an inch. These and control cuttings are set in a propagating frame as other cuttings. If the solutions are active the treated cuttings root abundantly in about a week whilst few, if any, roots appear in the control leaves. This test is claimed to be extremely sensitive and responds even with very dilute solutions.

The cuttings are stood in the solutions with their base immersed approximately 1 in. Basal leaves are removed as it is found that leaves which have been immersed tend to rot after planting. A convenient period of immersion is from eighteen to twenty-four hours. The environment of the cuttings during immersion is of importance. Temperature and humidity of the air affect the amount of solution entering the cutting and shading from strong sunlight and protection from dry air currents is advisable. It is also advisable to ensure that the bases of the cuttings are always in the solutions, during the treatment, to prevent wilting. After treatment the cuttings should be rinsed in water and planted in the normal way.

* The term "indole" is preferred by some to "indolyl".

The dust method. This has now largely replaced the solution method for practical work, the principle being to mix the crystalline substance with dusts such as talc or charcoal. Hubert, Rappaport and Beke (1939) found charcoal more effective than talc but talc is more commonly used. The main advantages of this method are that planting is carried out immediately and, as Grace (1937) found, a wider range of concentrations may be used with safety.

The dusts have been prepared in various ways. Grace (1937) mentions mixing by grinding. Laurie and Ries (1942) state : " The ideal method of mixing the synthetic growth substance in crystalline form with the talc is to place them together in the desired proportions in a small ball mill and allow them to mix thoroughly for two to three hours."

Stoutemyer (1939) describes a convenient and efficient method of obtaining an even distribution of the substances in talc. " Crystals of the growth substance are dissolved in sufficient 95% ethyl alcohol to make a pasty mixture when stirred into pharmaceutical talc. The mixture is dried with a fan circulation of unheated air, and stirred occasionally with a glass rod during the period of drying. When dry, the mixture forms a powder free from lumps. All dusts are stored away from light and heat in closed glass containers." At East Malling Research Station it is found that 25 grammes of talc can be made into a paste with 10 c.c. of alcohol. Where a range of concentrations is required a weighed amount of the substance is dissolved to form the strongest solution, and after setting aside part the remainder is diluted as required. In this way only one weighing is necessary and the relative strengths are accurate throughout the range.

The usual method of application is to dip the base of the cuttings, a number at a time, into water and, after shaking off excess water, into the dust so that the lower quarter to half an inch is covered with the dust. A light tap on the side of the vessel containing the dust will remove any excess and the cutting is planted immediately. Laurie and Ries (1942) state that hairy-stemmed cuttings such as those of pelargonium do not require wetting before dipping in the dust. The cuttings should not be planted by pressing them into the medium, as this removes most of the dust, but should be planted with a dibber, though no deeper than usual.

The injection method. Jackson (1939) and others, quoted by Feilden and Garner (1940), describes the injection of coffee cuttings with phytohormones as follows : " The solution of the growth substance is placed in a vacuum desiccator, and the bases of the cuttings are stood in the solution ; the lid is placed in position, and the air exhausted to a negative pressure of 60 cm. of mercury. The vacuum is maintained for a period of from 5 to 10 minutes during which time air is drawn from the interior of the cuttings and bubbles up through the solution. On releasing the vacuum, the solution takes the place of the air extracted from the cuttings, which are allowed to absorb the solution for from 5 to 10 minutes. Not only does this method reduce the time of treatment from 12-18 hours to a few minutes, but where large batches of cuttings have to be treated, it effects a considerable economy in the amount of solution used because the same solution can be used many times over." More than twice the number of injected cuttings rooted, but though various strengths of the proprietary Hortomone A were tried only a very few cuttings were rooted in each test. Injecting cuttings has its dangers with some subjects. Swingle (1929) found that injecting cuttings with water caused their death under the pressures tried. The author has caused similar damage in hardwood cuttings of quince (*Cydonia* spp).

The toothpick method. Smith and Romberg (1939) and Romberg and Smith (1939) describe a method of treating root cuttings and transplanted pecan trees with impregnated toothpicks in order to hasten new root growth. Pointed ends of ordinary round toothpicks were cut off to leave the middle portion 4 cm. long. These were soaked in desired solutions for 24 hours and then allowed to dry. For toothpicks carrying 4 mg. of indole butyric acid 1 gm. was dissolved in 21 c.c. of 95% ethyl alcohol. Each toothpick absorbed about 0·084 c.c. of solution. Holes the diameter of the toothpicks were bored through the roots and the toothpicks inserted. The treatment proved effective in increasing root production.

The soaking method. Leafless hardwood cuttings do not readily take up solutions when only their bases are immersed and other methods have been used. Injection by the sudden release of negative pressures has proved a risky procedure. Berry and Swarbrick (1940) obtained rapid rooting in defoliated hardwood cuttings of black currant (*Ribes nigrum*). Shoots of the variety Baldwin were collected on 3rd September, defoliated, cut into 9 in. lengths, and bundled

in lots of 15-20. Bundles of cuttings were stood upright in a solution of 20 p.p.m. β-indolyl-butyric acid for 24 hours at 40° F. The solution extended 4-5 in. up the cuttings. They were then removed and planted, in the bundles, into a peat-sand-soil medium in a cool greenhouse. The medium was well watered and the cuttings covered with sacks to keep them moist. On 30th November the cuttings were lifted and examined. The treated cuttings rooted much better than untreated controls, and basal cuttings more than middle or apical cuttings. It is suggested that cuttings might be rooted between September and December and immediately planted in the field, two cuttings planted together making an excellent "stool". (*See also below* Treatment after callusing.)

The spraying method. Tincker (1938) sprayed leafy cuttings with growth substance solutions after planting. No successful rooting was induced by spraying three times at intervals of two days. There was some leaf injury and defoliation. Tincker used somewhat strong solutions (100 p.p.m.) of indolyl-acetic acid.

The paste method. Laibach (1935), Fischnich (1935), and Laibach and Fischnich (1935) observed that roots could be produced on intact plants by dissolving β-indolyl-acetic acid in lanolin and applying this preparation as a paste to the stem. Requisite quantities of the growth substance are either mixed directly with warmed lanolin or first dissolved in alcohol. For example 0·5 gm. of the crystalline growth substance is dissolved in 10 c.c. of ethyl alcohol and then mixed with 50 gm. lanolin heated over a water bath. When cool the paste is applied by means of a glass rod to scraped surfaces or incisions at the base of the cutting or other plant part under treatment. Concentrations ranging from 0·01% to 2% are usual.

Winklepleck and McClintock (1941) describe the preparation of an emulsion which remains stable at room temperature and can be applied with a brush. Heat 7·5 gm. stearic acid, 2·7 gm. triethanolamine and 100 c.c. water till the stearic acid is melted. Stir to a creamy soap solution and add 38 gm. lanolin. Heat without stirring till the lanolin is completely melted. Hold just below 212° F. and stir vigorously until a thick, creamy, uniform emulsion forms. Allow to cool in a water bath with frequent stirring. By adding water, either before or after preparation, the emulsion can be given any desired consistency. Crystals of the growth substance are dissolved in a minimum amount of dioxane or other suitable solvent and are thoroughly stirred into the emulsion.

The continuous absorption method. Van der Lek and Krijthe (1937) describe a method they used which, though no positive results were achieved, is of interest. Little cups of solution were attached to the base of the cuttings which were set in a rooting mixture of sand and peat. Hitchcock and Zimmerman (1936) obtained increased rooting by attaching small vials of solution to individual cuttings for three to ten days before planting.

The vapour method. Zimmerman and Hitchcock (1939) and Zimmerman, Hitchcock and Wilcoxon (1939) report upon extensive trials in which plants were exposed to vapours of growth substances. Many species of plants were induced to form adventitious roots on leaves, stems, roots and cuttings. The plants were placed under bell jars with the volatile growth substances in open petri dishes or watch glasses. The amount disappearing in twenty-four hours was not discernible and many of the same samples were used repeatedly. Less volatile materials were placed with the plants under jars which were then partially evacuated. Another method was the placing of a warm to hot crucible beneath the dish or watch glass. The time of exposure varied from 10 seconds to 72 hours.

Molisch (1937) found that one effect amongst others of the vapours given off by ripening apples and other fruits was to influence the growth of roots. In small doses they stimulate growth, whereas in larger doses they retard it.

Denny (1939) working with potatoes, found that in the volatile chemicals, which have been shown to cause epinasty, the effective constituent derived from plant tissue is ethylene and not any of the other epinasty-inducing, volatile chemicals tested by him.

(ii) Treatment after callusing. Stoutemyer, Jester and O'Rourke (1940), working with black locust, obtained the best results by treating the cuttings with growth substance after callusing. This prevented injury due to the high concentrations found necessary to promote good rooting. The cuttings were packed in a container with moist sphagnum moss and left for ten days at from 68°-80° F., by which time callusing was abundant. They were then removed

and stood with their bases in an aqueous solution, containing 100 mg. per litre of indolyl-acetic acid for twenty-four hours. The treated cuttings were then stored for a period at 70° F., to allow root primordia to form under favourable conditions, after which they were planted either in the field, where 69% rooting was obtained, or in a greenhouse, where 90% rooted.

It was found at the Ceylon Tea Research Institute (1941) that treatment of tea cuttings after callusing for a month in half sand and half peat gave improved results.

(iii) Results. The effect of hormone treatment upon rooting varies greatly. Pearse (1939b) lists 319 species tested by various workers. In some of the cases cited the treatment conferred no benefit whilst in others where the control cuttings failed to root, those treated rooted 100%. Failure to obtain favourable response to treatment with phytohormones is probably traceable to the use of unsuitable cutting material. Pearse (1939a) showed that the selection of cutting material is of the utmost importance. Thus the condition of the parent shoots, whether growing or with growth stopped, and the source, whether mature established trees or those newly planted, are factors which play a great part in governing the rooting response obtained after treatment. Some of the cases cited by Pearse (1939b) are as under. The figures are per cent. rooted :

Subject	*Treated*	*Control*
Cydonia oblonga	60	20
Morus alba	76	47
Prunus avium	90	nil
Prunus cerasifera	100	80
Prunus cerasus	90	40
Prunus domestica	80	10
Pyrus communis	90	0
Pyrus malus	50	0

Clearly the benefits to be obtained are considerable and are ample reward for the slight extra trouble involved.

The advent of these aids does not mean that other factors may be neglected. Watkins (1940b) in welcoming the use of synthetic growth substances points out that none of the usual care must be omitted. Laurie and Ries (1942) emphasize that treated cuttings require the same favourable conditions and watchful care demanded by untreated cuttings.

Overdosing seriously inhibits new shoot growth and it appears that the dose must be worked out for each variety of plant according to both internal and external conditions of the cutting. Pearse (1939a) claims that given optimum treatment the subsequent growth of treated cuttings is at least as good as that of cuttings rooted in the normal way. Chadwick and Kiplinger (1939) observing the growth of ageratum and poinsettias found that if treated and untreated cuttings were removed from the propagation bench at the time the untreated cuttings had rooted, the ultimate growth was the same.

Chandler (1942) is somewhat pessimistic. He states that there is as yet no good evidence to give hope that by treatment with auxin (growth controlling substances) alone, or with auxin followed by any other substance, propagation by stem cuttings can be made economical practice for any deciduous orchard varieties not now propagated in that way.

It is to be regretted that the subsequent growth of rooted cuttings is rarely detailed beyond the propagation bed. In some cases, it must be admitted, as Swingle (1940) quotes, " the operation was a success but the patient died ". Nevertheless, growth substances are proving another extremely useful weapon in the hands of the practical propagator. They hasten the formation and increase the amount of new roots. They therefore shorten the time during which they remain in the propagating frame needing highly skilled attention.

(*b*) Other substances

(i) Sugar. Many attempts have been made to increase the food supply in cuttings prior to planting. Curtis (1918) and Chadwick (1929) found that standing cuttings in sugar solutions before planting improved their subsequent rooting. Knight (1926) stood hardwood deciduous cuttings in 10% cane sugar for three days before planting and observed an increased production

of callus and roots. He found the effect to vary from season to season but was unable to determine the cause. There was no selective absorption, and the concentration of the solutions remained unchanged, although the volume absorbed varied with the concentration. The absorbed sugar rapidly accumulated in the leaves.

Chadwick (1932) increased the rooting of cuttings of *Taxus cuspidata, Ligustrum vulgare* and *Ilex verticillata* by treating the cuttings with sugar solutions. One pound of cane sugar in seven gallons of water proved the most effective. The cuttings were placed with their bases $1\frac{1}{2}$ in. in the solution for from twelve to thirty-six hours. They were then thoroughly washed to remove adhering sugar and so avoid the development of fungal and bacterial action which otherwise is almost certain to develop.

Doran, Holdsworth and Rhodes (1940) treated white pine cuttings with sucrose before treatment with growth substance and found that the cuttings lived longer whether rooted or not.

(ii) Ethyl alcohol. Clements and Akamine (1940) soaked sugar cane sets in ethyl alcohol solutions prior to planting. The root tips are already formed in the cane and should the cane come in contact with the soil these primordia soon develop into normal roots. Any treatment merely affects the development of these primordia and is quite different from root initiation. Soaking the sets in a 5% solution of 95% ethyl alcohol for either 24 or 48 hours was the standard treatment. A very marked increase in root production was noted, especially at marginal temperatures, and it is suggested that stimulation with alcohol is caused by its being a readily available, high-energy-containing food.

(iii) Honey. Oliver (1939), using cuttings of pyramid cedar (*Thuja occidentalis pyramidalis*) found that standing the cuttings in a 25% solution of honey for 24 hours gave 64% rooting as against 25% stood in pure honey. None of the control cuttings had rooted at twelve weeks after planting. Chrysanthemum cuttings were similarly treated. More cuttings rooted than with control treatments and the response was only slightly less than with the most favourable hormone treatment used.

(iv) Infesting insects. The use of cuttings free from systemic diseases is of vital importance, but material infested with insect pests, not carrying such diseases, can be cleansed before planting. Conceivably the condition of material used as cuttings might be improved by insect colonization. So far results have proved disappointing. Deuber (1940) found that conifer cuttings from trees infested with spruce gall aphid generally rooted less than those from uninfested trees. The writer has used aphis infested softwood cuttings of cherry, both *P. avium* and *P. cerasus*. Both infested and clean cuttings were dipped in nicotine-and-soap solution immediately before planting, in order to kill all insects. The infested cuttings dropped their leaves within a fortnight and failed to root. The clean cuttings retained their leaves and behaved normally.

(v) Sealing materials. Berry and Swarbrick (1940) describe the use of protective coverings at the base of black currant hardwood cuttings to prevent rotting. They tested petroleum jelly, paraffin oil (kerosene), paraffin wax, cuprous oxide, zinc oxide and $2\frac{1}{2}$% and 5% solutions of cellulose acetate in acetone and dioxan. The cuttings were planted in soil in pots in an unheated greenhouse on 21st February and examined on 29th March. No rotting had occurred. All except the paraffin wax treated cuttings had grown shoots. Root growth was almost entirely inhibited by cuprous oxide, petroleum jelly and the oil, though no stem injury was seen. The 2·5% cellulose acetate in acetone gave slightly better rooting than that in the controls. El Azouni and Cameron (1940) showed that a proprietary bitumastic known as " Tree Seal " in the U.S.A. stimulated the growth of callus and adventitious buds in disbudded citrus stems.

In connection with the sealing of cuttings and the interruption of the free entry of water it is of interest to find that Evenari and Konis (1938) attribute wilting of cuttings to the presence of lanolin at their base which they used as a vehicle for growth substance treatment.

Grace and Farrar (1941) sprayed Norway spruce cuttings with a wax emulsion designed to reduce transpiration in transplanted conifers. The emulsion, diluted with two volumes of distilled water, was sprayed over the entire cutting, with the exception of the basal two centimetres, before planting. This had no effect on dormant cuttings but was markedly injurious

to summer cuttings. Injurious effects were reduced when wax was combined with growth substance treatment.

2. TEMPERATURE, LIGHT AND MOISTURE TREATMENTS

Once the cutting material is removed from the parent any treatment given to it will be confined to this material and there will be no modifying reaction of the mother plant. The cuttings occupying comparatively little space are conveniently placed under special local conditions (*see* page 33).

(*a*) Temperature

In cuttings of *Pinus* the outflow of resin at the basal end is copious and it is usually considered advisable that it should be checked. Bayley Balfour (1913) accomplished this by the simple process of plunging the cut end of the cutting in nearly boiling water. The resin canals were sealed and, at the same time, in Bayley Balfour's opinion, the heat stimulated the formation of callus.

It should be recorded that Deuber (1940) found that with *Pinus strobus* cuttings better results were obtained when the resin exuding at the base was not removed.

Schwarz (1933) found that warm water bath treatment assisted the rooting of cuttings of some species, notably numerous *Erica* species, *Azalea indica* and the rose Ulrich Brunner. Treatment for 12-14 hours at 30° C. during the rest period produced good results. In the case of leafy cuttings the superiority or the reverse of total immersion depends on the resistance of the leaves, which varies in different plants.

In countries having severe winter climates cuttings are often collected in the autumn, stored through the winter and planted in the spring. The storage period is a convenient time in which to impose special conditions. Chadwick (1931) found that storing hardwood cuttings at 60° F. for two weeks and then at 40° F. for the remainder of the winter was better than continuous storage at 40° F. Continuous storage at 40° F. combined with a final two weeks at 60° F. was definitely deleterious. Chadwick explains that "Buds on cuttings taken in November are in a resting condition, but since the root initials and meristematic tissues at the base of the cutting have no resting stage, the high temperature at the start of the storage period enables callus and root initial development to proceed at a more rapid rate than would occur at the lower storage temperature. Thus at the time the temperature is lowered the basal cut is well healed and undoubtedly considerable root initial development has occurred. The 40° F. throughout the winter is sufficient to hold the root development in check and at the same time to break the rest period of the buds. Very little, if any, shoot development occurs at this temperature. When the cuttings are lined out in the spring the roots and shoots are ready for simultaneous development."

Tukey and Brase (1935) using clonal quinces Malling A and B, in one season, obtained 78% and 83% success from autumn collected wood as against 3% and 13% from spring collected wood. In this experiment the autumn wood was collected in November and stored in a nursery cellar in sand and the cuttings were made in late February and early March. Thus the pre-callusing described by Chadwick did not operate in this case and some other factors were responsible. Tukey and Brase state that there was no noticeable winter injury to the spring collected wood and the poor stands achieved cannot thus be accounted for.

Van der Lek (1933) using blackcurrant (*Ribes nigrum*) hardwood cuttings in cold storage experiments obtained no effect unless the cuttings were treated at the end of the rest period. When material was taken in February and treated during March, cuttings cooled below zero rooted much more freely than those subjected to temperatures of 2° C. and 9° C. Callus development was also increased by pre-cooling. Van der Lek suggests that some growth stimulant may be associated with storage starch and that cooling makes this available through its influence on carbohydrate metabolism.

(*b*) Light

Considerable attention has been paid to the effect of light upon intact plants but little, if any, to the effect of light upon cuttings between collection and planting. Avery and others

(1937) have found that light has a bearing, directly and indirectly, upon hormone production, and Oinoue (1936a) discusses the transmutation of stem into root and *vice versa*, which is brought about by darkness and light respectively, given a suitable moist atmosphere and sufficient warmth.

(*c*) **Moisture**

The chief concern of propagators is to prevent the drying of cutting material between taking and planting ; this is especially important with leafy cuttings which lose water very rapidly. Practical methods of preventing, or reducing, water loss usually consist in providing intimate moist atmospheres by wetting the cuttings and surrounding them with moist material. Leafless cuttings are often heeled in until planting time. It is rare to find recommendations for the drying of cuttings. Bayley Balfour (1913) cites a case in which cuttings may be allowed to dry slightly before planting. These are cuttings of the apex of vigorously growing shoots which may be checked by drying. The food supply within the cutting is required for callusing and rooting, and if used for extension of the shoot none will be available and the cutting will not survive.

Calvino (1937) describing the use of leaf cuttings for the propagation of " bowstring hemp " (*Sansevieria stuckeyi*), a liliaceous subject, says the leaves are torn or cut from the plant and dried in the open under shade for 15 to 25 days before setting in a shaded bed of sandy soil.

Practical propagators are in the habit of allowing cuttings of hairy leaved plants, such as pelargoniums and succulents, to dry in the sun before planting. The operator's explanation that this treatment makes the cuttings " hungry " and so encourages quick rooting in order to obtain nourishment is probably not the whole story.

Graham (1934) stresses the importance of preventing wilting in leafy cuttings. In dealing with apple cuttings, which are particularly liable to water loss, he severed the cutting under water.

In attempts to keep up the supply of moisture in cuttings Vekhov and Iljin (1934) made the basal cut under water and obtained better rooting in *Fraxinus viridis*, *Acer dasycarpum* and *Acer platanoides*. When the method was applied to *Quercus rubra*, *Cotinus coggygria* and *Betula verrucosa* negative results were obtained. Cheesman and Spencer (1936b) when collecting cuttings of cacao had a bucket of water alongside in which the cuttings were placed immediately they were severed from the parent. The authors state that it might be even better to cut under water but suggest that this is scarcely feasible. In connection with this it is noticed that McDermott (1941) and Gibbs (1942) when examining samples of tree branches for water content found that the consecutive cutting of portions at intervals of 15 to 30 seconds gave significantly different results from portions where both ends were cut simultaneously.

Swingle (1929) soaked apple hardwood cuttings one hour in water and obtained increased rooting. Soaking for a period of forty-eight hours retarded rooting and any water treatment he used retarded the formation of callus. Injecting the cuttings with water was deleterious. This harmful effect may have been due to the severity of the treatment, the cuttings being placed in a closed chamber under reduced pressure for 15 minutes and for 22 hours after release of pressure. The placing of leafy cuttings in water for more than a very short time is generally agreed to have a harmful effect. For example, Hubert and Beke (1938) specially used extra controls in hormone solution treatments because they found that standing cuttings in water had a bad effect on some species. Sledge (1930) points out that when a cutting is cut the base becomes injected and that this plays an important part in the initiation of cambial activity at the base of the cutting.

The reduction of water loss from leafy cuttings is often brought about in practice by the removal of part of the leaf area. Biale (1939) found that upper or lower leaves may be removed with equal effect upon water loss. In removing leaves it must be remembered that any reduction in leaf area may reduce rooting, other conditions being satisfactory.

3. WOUNDING

Sledge (1930) suggested the importance of the distribution of air in the intercellular spaces of the shoot when a cutting is wounded. It becomes injected in that region and local cambial

activity is stimulated leading to the formation of " wound roots ". Various workers, Day (1932) and Stuart and Marth (1938), have reported that wounded cuttings have given better results than those not so treated. It follows that every cutting is " wounded " in preparation and the size and shape of these wounds has been studied in relation to subsequent rooting. In general the angle of the basal cut has had no appreciable effect. Longley (1942) found this true of the many greenhouse plants that he studied.

Practical propagators sometimes slit cuttings about an inch upwards from the base before planting. Wóycicki (1938) obtained better rooting in carnation cuttings so treated.

In combination with hormone treatment the slicing, scraping and other extra wounding at the base of the cutting has a beneficial effect probably due to a greater intake of the material. Chadwick and Swartley (1941) obtained heavier rooting in cuttings of *Juniperus chinensis* and *Taxus cuspidata* by slicing before treating with synthetic growth substances.

The paring of callus formed at the base of cuttings might be considered as the application of a stimulant after planting but comes more naturally under " Wounding " seeing that it is followed by replanting. Softwood cuttings, of many species, may form large basal calluses and remain alive a long time, before finally dying, without forming roots. Bayley Balfour (1913), speaking of wounds stimulating root formation, states that by paring the surface of callus-tumours it is possible to stimulate almost immediate root-development. If a first paring is ineffectual a second or third may bring about the desired growth. Priestley (1926) states that " in many plants they (the roots) grow out through the pad of callus which covers the cut end of the shoot . . . when the callus is pared down its growth will be reduced and the food supply it draws upon left available for the vascular cambium within, which grows more actively, with, as a result, the production of root initials ". Kemp (1936a) studied the effects of callus paring on root production in cuttings and found that as the structure and origin of callus varies in different species it is futile to generalize on its anatomy and formation. He found that the paring of callus in the case of *Camellia sasanqua* removed the potentiality of root-production and had no influence on the rooting of *Viburnum grandiflorum*. Kemp says " it remains to be proved whether callus-paring is conducive to root-formation in cases where the roots are produced from a callus which in structure resembles that described by Simon (1908) in *Populus* ". Simon (1908) found that in *Populus* the cambium was situated deep in the callus tissue. Both Bayley Balfour and Priestley probably had this type of formation in mind when describing the benefits of callus-paring.

4. NURSE GRAFTING AND OTHER AIDS

The Northern Spy apple, sometimes used as a rootstock for apples in Australia, South Africa and elsewhere, serves as an excellent example of cutting-grafting. Davey (1929) describes this process in which the scion is a one-year shoot and the stock a root cutting of the same variety. When grafted they are set in the soil as cuttings, which, after establishment, are used as root-stocks for other varieties. If it were economical to propagate Northern Spy by ordinary cuttings the grafting process would not be necessary. It appears that each supplies something the other lacks.

With no knowledge of phytohormones one might very well expect roots to be capable of producing roots just as stems produce stems. That this does not follow has been observed by numerous workers. For example, Upshall (1931) working with apples obtained shoots on root cuttings but found further root growth definitely limited. Similarly Hoblyn and Palmer (1934) working with Pershore plum found that root cuttings made shoots but not roots and in the end failed to survive.

Upshall (1929) by grafting a short piece of one-year-old apple seedling root on the upper end of a variety root cutting induced the latter to grow new roots (*see* Age of parent, page 11). He thought that the piece of seedling root transferred something to the variety root cutting. This suggestion was borne out by later work. Moshkov (1937) and Snow (1940) state that hormones can pass across the union of two plants or across moist cut surfaces of shoots in contact.

Halma (1931), Richards (1936), and Halma and Eggers (1937) found that leafless cuttings of citrus could be induced to root by grafting them with leafy scions. They pointed out that success depends upon the retention of leaves by the upper cutting.

Bouillene and Went (1933) noticed that cuttings on which leaves had been grafted, and which rooted vigorously, frequently gave abnormal thickenings near the root tip, doubtless due to the excess of auxin coming from the leaf. On removal of the leaf the roots resumed their normal growth (*see* Leaves, page 15).

Cutting-grafting is used in special cases. Kerr (1936), in order to obtain fruit trees on their own roots, placed his stem cuttings (scions) on inverted root pieces and obtained scion rooting more quickly than normally. Andreichenko (1937), having difficulty in rapidly multiplying gooseberries (*Ribes grossularia*) by ordinary cuttings, grafted them upon cuttings of the more ready rooting black currant (*Ribes nigrum*) and obtained good success.

Various methods of cutting-grafting have been in use for a long time. A number of these are described by Baltet (1923). Plants which root poorly as cuttings are grafted upon cuttings of ready rooting related subjects and by deep planting the upper cutting " scion roots ". When established upon its own roots the stock or lower cutting is removed. This is sometimes termed nurse-grafting. Lincoln (1938) and others have planted grafted apple trees deeply in order to encourage scion rooting and to provide scion varieties with their own roots.

Hatton and Bagenal (1933) found that the rooting of scion varieties of apple, pear and plum was dependent upon the scion variety and also, apparently, on the degree of stock/scion compatibility. In pears, for example, the four varieties, Fertility, Emile d'Heyst, Durondeau and Dr. Jules Guyot worked upon incompatible quinces scion-rooted when the graft-union was buried by soil cultivation. On the other hand the variety Conference, which is happier on quince, was not seen to scion root on any quince rootstock. In general it would appear that scion rooting is readily brought about by working either upon relatively dwarfing rootstocks or by the use of incompatible stock/scion combinations, provided the scion is in contact with the soil. Inverted root pieces used by Kerr (1936) could be regarded as forming an incompatible union with the scion.

SUMMARY

1. Synthetic growth substances, applied in many different ways, have given varying results. Used discreetly, in conjunction with good cultural practices, they assist rooting. Sugars and other substances absorbed by cuttings have sometimes improved their callusing and rooting.

2. Subjecting cuttings to periods of warmth before planting has increased subsequent rooting. Illumination of the roots of intact plants causes the development of stem tissue and stems take on a rootlike nature in the dark. Retention of moisture in cuttings is aided by local moist atmospheres and materials. Neither moisture nor temperature nor—probably—light effects should be considered separately.

3. Wound stimulation, especially in conjunction with external growth substances, can increase the rooting response in cuttings. Response to the paring of callus depends on the position of the cambium within the callus mass.

4. Shy rooting root cuttings can be induced to root by grafting upon them either stems or ready rooting pieces of root.

Shy rooting stem cuttings grafted upon pieces of root and planted deeply often form roots from the stem.

Leafless stem cuttings are induced to root by grafting leafy stems upon them ; it is concluded that the leaves provide substances necessary for rootgrowth.

C. PLANTING AND SUBSEQUENT TREATMENT

1. MEDIUM AND SPACING

The study of various media and their effect upon the rooting of cuttings has received a great deal of attention over many years and detailed reports upon the subject have taken up much space in the literature. In general softwood cuttings demand special conditions, whereas hardwood cuttings and root-cuttings are more tolerant. Sorauer (1895) states that in cuttings it is essential to bring about a sufficient closing up of the cut end of the shoot. This process

takes place, with very few exceptions, more completely when the cut surface is well supplied with air. Care must, therefore, be taken that the medium is very thoroughly aerated. Bayley Balfour (1913) wrote that at the basal end of the cutting there should be adequate heat and aeration.

Practical propagators have found that cuttings placed at the edge of porous pots often root better than when in the middle and this they attribute to good aeration. Various devices are used to increase aeration still further. One of the simplest is that in which a smaller pot is set within the larger and the medium confined to the space between, the inner pot being filled with crocks to hold moisture. Another device is the invertion of the smaller pot so that the space occupied by the medium becomes narrower as the depth increases.

The most successful media for the rooting of cuttings have all been of open texture. Knight (1926) using hardwood cuttings found that a clay medium favoured callusing and sand favoured rooting. He, therefore, transferred his cuttings from clay to sand between callusing and rooting but was unable to increase rooting over those always in sand. He found that callus formation was related to high water content of the medium. White (1942), in his tissue culture experiments, found that in the presence of a liberal supply of oxygen, tumour-like growths would proliferate in all directions. When oxygen is reduced, when portions sink below the surface of the nutrient, development of stems and leaves begins. Brought up to the air again the original formless condition would reassert itself. These results are apparently conflicting but the comparison of cuttings in soil with isolated tissue in culture solution is probably not justified. Hardwood cuttings are often successfully rooted in open textured soils with a high water table. In parts of Holland and elsewhere the soil formation appears to be very suitable for propagation by cuttings. In essentials it is a layer of open textured soil overlying a layer of peat or similar material through which water moves freely and is varied in depth by the raising and lowering of water in the nearby dykes by the operation of sluices. The water is not permitted to rise above the base of the cutting. The rising and falling of the water is thought to improve the aeration of the medium by its pumping action. Vyvyan (1943) describes experiments in which these conditions were imitated. A three-inch layer of sphagnum moss or spent hops was placed beneath a nine-inch layer of sand in the open. Hardwood cuttings of plum rootstock were planted in the sand with their bases just above the humus layer. In almost every case a higher percentage rooted over the humus layers than in control sand beds and the cuttings were larger. Vyvyan suggests that " the best plan would be to look for some place where such a layer normally exists ".

Bailey (1920) and many others definitely state their preference for sand as a medium for indoor use. Coarse sands or even fine gravels have been advocated because of their excellent drainage and freedom from organic matter bearing organisms which cause rotting. Starring (1924) writes that nitrate-free material should be used for rooting media. He suggests that the low nitrate content of sand may be one reason why it has been found better than good soil for cuttings.

In experimental work sand has distinct advantages over many other materials. Pearse (1939b) states that for controlled experimental purposes sand is probably the best medium as it can be most readily freed from traces of unknown substances which may affect root formation in media of unknown composition such as peat and peat moss.

(*a*) **Sand**

There are many types of sand in use by propagators. Very fine sands pack badly and are to be avoided. Pyke (1931) describes two sands he used as media for softwood cuttings of cacao in Trinidad. " One was a fine brown sand with small angular grains which proved unsatisfactory, probably because of its liability to pack and become waterlogged. The other, a coarser beach sand was much better. This sand, of a round even grain, between 0·5 mm. and 1·0 mm. diameter, drains quickly."

Graham and Stewart (1930) state that at Edinburgh the substitution of quartz sand for river sand reduced the rooting period by one-third. Goehde (1938) as reported by Swingle (1940) concluded that the acidity of the sand was the most important consideration. In general he found that a pH of 6·0 or less was preferable. The sand used at Edinburgh, though so different

in its influence on rooting, varied little in reaction. The quartz sand had a pH of 7·1 and river sand a pH of 7·3. Apparently the mechanical effect outweighed the possible effect of reaction. Kains (1931) writes that the chief material for indoor use is sand. " The grade should be sharp, clean and as free as possible from organic matter. If the greater portion will pass through a sieve of eight meshes to the inch, but not through one of twenty-five, the range will be about right."

Swingle (1940) quotes Wóycicki and Terpinski (1937) who show that the moisture of a sand medium has a marked effect on rooting. Sand with 25% water-holding capacity was unsuitable since most of the cuttings withered in spite of frequent syringing. They considered a holding capacity of 50% to 75% was best, but this differed somewhat amongst the various plants used.

Even the best sand has drawbacks compared with some other materials. Graham (1934) stresses the importance of removing cuttings from sand as soon as rooted because of lack of nutrients in the sand. Roots are often more brittle when grown in sand. Chadwick (1932) found that roots produced on *Taxus* cuttings placed in a peat medium are much more flexible than those produced on cuttings in sand. It would seem then that transplantation from sand media, especially those of the coarser kind, is not so easy as from peat. Laurie and Chadwick (1938) point out that sand is about ten times as heavy as peat. This naturally increases the cost of handling.

Watkins and Blackmon (1941) working with ornamental plants in Florida found that admixtures of several organic substances with sand were helpful in the propagation by cuttings of a number of ornamental plants which root shyly.

(*b*) **Sand mixtures** (*See* Peat and peat mixtures.)

(*c*) **Pumice**

Graham (1934) reports the use of ground pumice as a rooting medium at the Royal Botanic Garden, Edinburgh. He found that when available locally it could be considered a fair substitute for quartz sand.

(*d*) **Peat and peat mixtures**

Hitchcock (1928) carried out extensive trials with peat moss, peat moss mixtures with sand and sand alone. He found it important to allow for seasonal variation in testing the rooting response of cuttings in the various media. Of 96 varieties (46 genera) only 5 failed to root best in a mixture of equal proportions of peat moss and sand. Hitchcock states that the efficiency of this mixture is due mainly to its high moisture-retaining capacity, to the presence of growth-promoting materials furnished by the peat moss, to efficient aeration and in some cases, in *Azalea* for example, to its acid reaction.

Esper and Roof (1931) in experiments in the autumn and winter with slag, sand, peat, equal mixtures of peat and sand, and peat and slag tested nine species. The conclusion was that slag and peat together form a very desirable medium. The slag registered pH 8 and the peat pH 4, hence the mixture was slightly acid.

As already noted the type of root produced is affected by the medium. Chadwick (1932) found that the use of sand and peat mixtures, rather than sand, will often result in a better massing of roots at the base of the cutting. In ordinary nursery practice surface rooting of cuttings is taken as an indication that the medium is insufficiently aerated.

Hubert, Rappaport and Beke (1939) experimented with ten different media, firwood soil, oakleaf soil, sawdust, river sand, coal ashes, peat and sand, peat, garden soil, rotting refuse and loamy sand. The mixture of peat and sand, and the peat alone proved the best. Untreated cuttings rooted almost as well as cuttings treated with indolyl-acetic acid and the writers came to the conclusion that the beneficial effect of the peat media might be due to stimulating substances in the peat.

John Innes (1941) Horticultural Institution advise a compost for general use in striking cuttings. Loam 1 part, peat 2 parts, and sand 3 parts. They advocate sterilization of the

media by heat but point out that the substances should be sterilized separately before mixing and that clean fresh sand and peat do not need sterilizing.

Peats vary much in composition according to origin. The peats used as media for propagation are sphagnum moss peats which have been disintegrated and graded according to quality, Dachnowski-Stokes (1931) and Johnstone (1931).

Moss peats vary in reaction but are considerably more acid than sedge peats, generally occupying the range pH 3·0 to 4·5. They are slow to decompose and, as Johnstone (1931) records, unless the incorporation of peat with soils is accompanied by applications of nitrate and other plant food, the cellulose-decomposing bacteria will utilize these foods to build up their own bodies with consequent shortage of nitrates, etc., available to the plant, which would account for the apparently depressing effect of peat. Laurie (1930) states: "Additional applications of nitrogen will prove beneficial with many crops. Similarly superphosphate applications along with peat are likely to prove beneficial."

(*e*) Peat added to soil

Johnstone (1931) remarks that the quantity of peat added to soil is likely to be governed by costs. Up to 5 tons per acre may be regarded as beneficial for improving soil texture but the thorough mixing with the soil is important. Dung or artificials should be used in conjunction with it.

It is generally stated that peat increases the moisture holding capacity of the soil and doubtless this confers benefits, but, as Feustel and Byers (1936) point out, the incorporation of peat with soil does not of itself increase the amount of moisture available to the plant. The textural and other physical and chemical effects must be taken into account.

Tukey (1941) considers that the incorporation of peat in garden soils, usually rich in nutrients, often gives a better return than further applications of fertilizers. He cites peat moss and sedge peats as under and stresses the importance of differentiating between peats according to their origin.

	Organic Matter.	pH.	Nitrogen.	Ash.
Peat Moss ..	98%	3.0 to 4.5	1%	1.5 to 3.0%
Sedge Peat ..	80 to 95%	4.5 to 6.0	2.0 to 3.5%	5 to 30%

Good quality dry peat absorbs up to thirty times its own weight of water and it is, therefore, important to moisten it thoroughly prior to its incorporation in the soil. The poor effect of peat mulches outdoors sometimes reported, Johnstone (1931), is attributed to the impervious condition of dry peat. Laurie (1930) reports that under glass peat mulches have proved beneficial to many plants.

(*f*) Acid media

Small (1923) conducted various small scale experiments in which cuttings in coconut-fibre media were watered with dilute acids and came to the conclusion that watering with vinegar at the rate of three teaspoonfuls to the gallon of water aided root production. Small followed this by placing cuttings of *Aucuba japonica* in two jars of water, through one of which carbon-dioxide was "bubbled" once a week for four weeks and air through the other. With twelve cuttings in each jar eight rooted and developed twenty-four roots under CO_2 treatment whilst only six rooted and developed fourteen roots under the air treatment.

Kemp (1936b) reviews the previous work with acid media including Small's, and states that the conclusions reached are not supported by fact and the suggestion that plants root best in soils having similar reaction to that in which they normally grow well is totally unsupported. "The relative ease with which so many species from widely divergent types of soils are found to root, side by side, in propagating cases at Edinburgh where the external factors are uniform, supports this attitude."

Hitchcock (1928) working with granulated peat moss has found that it will leach sufficiently, in the course of an experiment lasting six to ten weeks, for a change of pH 0·4. Thus initially its pH was 3·6, finally it was 4·0. *Rhododendron maximum* cuttings formed excellent root systems in a leached peat moss which had already been used. The reaction of this medium four months after the original leaching, and at the time the rhododendron cuttings were well rooted, was pH 6·76, showing practically no tendency to revert to the acid form. Hitchcock stresses the inadvisability of relying on results obtained with liquid media to explain responses with solid media thus, " it does not appear that data obtained for cuttings rooted in liquid media can always be used to explain the limiting factors for root production in solid media ".

Watkins (1940b) working with azaleas found it necessary to correct alkaline irrigation water by the addition of one pint of acetic acid to 50 gallons of water. He explains that alkaline water renders vitamin B_1 ineffective and it is therefore necessary to use water of acid reaction.

(*g*) **Water**

Zimmerman (1930) rooted leafy and leafless dormant cuttings in aerated water but not in water devoid of oxygen. Running water proved equal to aerated water. Oxidizing agents, introduced into the water, such as potassium permanganate and hydrogen peroxide increased the amount of rooting but were not so effective as aeration. The Indian Tea Association (1942) report that tea cuttings rooted well with the proximal end immersed in water.

(*h*) **Saturated air**

Bailey (1917) describes a device used for the propagation of pitcher plant (*Nepenthe* sp.) using saturated air as a medium. These plants root near the surface of their natural medium where there is abundant aeration. Cuttings are placed through the drainage hole of an ordinary porous clay pot so that the base of the cutting is inside the pot. The cutting is wedged in the drainage hole with a small stick. At the Royal Botanic Gardens, Kew, England, the cuttings are wedged by means of a little sphagnum moss pressed tightly around the cutting to a depth of about half an inch. The pot is then inverted and placed upon moist peat, or fibre, within a closed case, with bottom heat. Rooted cuttings are transferred to a light peat compost or fibre as used for orchids.

Pirone (1941) rooted both hardwood and leafy cuttings in a special box which he tentatively named " Rutgers Aero-propagator ". The rooted cuttings were later successfully transferred to soil. The box is divided into two chambers by a rubber sheet supported by numerous cross laths. The cuttings are pushed through small holes in the sheet into the chamber containing saturated air provided by water vessels from which hang strips of wet cloth. The chamber containing the distal end of the cuttings is covered with a sheet of glass to conserve moisture as required.

Carter (1942) used a somewhat similar device but possibly of wider application, in order to study root growth of pineapples. The plants were supported with their roots in a chamber kept moist by an atomizing device. This permitted a very fine jet of water to impinge on a metal plate, which resulted in a steady drift of finely divided spray. Domestic water supply is adequate and by a simple modification nutrients were conveniently introduced at will.

Potter (1936) placed blackberry root cuttings in a moist atmosphere in February and transplanted them when they had developed shoots. The cuttings were 2 in. long and were laid flat in shallow boxes, without soil, in a propagation house at 55°-60° F. The cuttings were sprayed with water two or three times a day and shaded with sheets of paper. In a month the John Innes variety had formed shoots on all cuttings and these were planted in sandy compost after removing all but the best shoot on each cutting. The young shoot stood above the surface of the medium. They were placed in a warm house until roots had formed when they were gradually hardened off and transplanted to open nursery ground in May.

Stoutemyer, Maney and Pickett (1936) placed six-inch root pieces of Virginia crab horizontally on the surface of moist sand within a closed frame with high humidity and temperature 75° F. Roots taken in November developed shoots several inches long within two months, when they were divided into single shoots with 1 in. to 2 in. of the original root piece adhering. When planted in moist sand, within a propagating house, roots developed abundantly.

(*i*) **Sphagnum moss**

Live sphagnum moss has attracted some attention as a rooting medium. It is antiseptic and has been found to prevent diseases, amongst which is the damping off of seedlings as described by Hope and others (1941). Witt (1928) was successful in rooting softwood cuttings of walnut (*Juglans regia*) and a walnut hybrid (*J. nigra* × *J. californica*) in it. The most successful medium consisted of three-fourths chopped, live sphagnum moss and one-fourth quartz sand. The cuttings were placed close against the side of a 2 in. pot, commonly termed a "Thumb" pot, into which the medium was tightly pressed before plunging in a closed case with bottom heat 70° to 75° F. and top heat some 5° lower. Vekhov and Iljin (1934) found that sphagnum moss and sand mixture gave better results as a medium than sand alone. Kains and McQuesten (1938) list sphagnum moss as a medium "used to some extent". The dearth of literature is apparently not a reliable measure of the extent to which sphagnum moss is used in general horticultural practice, where its freedom from fermentation and excellent aeration is appreciated. In one trial with leaf-bud cuttings of Cumberland black raspberry Garner and Hammond (1939) found that cuttings in sand produced shoots before roots whilst those in live sphagnum moss produced roots before shoots (*see* Sphagnum moss, Watkins (1940b)).

(*j*) **Charcoal**

Appleyard (1915) reports upon numerous references to the use of charcoal as a medium for plant growth and quotes, amongst others, the *Gardeners' Chronicle* of 1841, page 537. "It is said to be the means of making the most difficult kinds of plants strike root readily from cuttings." Appleyard also quotes *Hovey's Magazine of Horticulture*, of a little later date, "*Combretum purpureum*, a plant not easily increased, is speedily rooted in charcoal." These good reports are not maintained to the present day. Modern comment upon the use of charcoal as a medium for rooting cuttings is meagre and disappointing.

Shaw (1919), in attempts to improve the rooting of apple variety cuttings, used powdered charcoal both alone and as a half-inch layer over sand with the hope that it might check rotting. Very poor results were obtained.

Traub and Auchter (1933), studying germination media for avocado and mango, found that of sixteen media those containing charcoal were generally best under conditions of high moisture and temperature.

(*k*) **Coconut fibre**

Graham and Stewart (1930) found that coconut fibre answered well as a medium in heated frames. From Tanganyika (1939) come reports upon trials with peat moss and sand and coconut fibre and sand in which the latter proved to be an efficient substitute for peat moss and sand, though rooting in it of *Coffea arabica* was somewhat slower. Coconut fibre has the advantage of being readily available in the tropics. It should be well-rotted and soft so that, when broken up and sifted, there are no small hard lumps.

2. DEPTH AND ANGLE OF PLANTING

Depth of planting cannot properly be considered apart from the length of the cutting, for in the main it bears a proportional relation.

The conditions at the base of a cutting in a given medium are governed chiefly by the depth of planting. Both temperature and moisture fluctuate more near the surface than deep down and the upper layers of a medium are likely to be better aerated. These conditions are largely under control in closed frames used for the propagation of leafy softwood cuttings and the presence of other factors in the propagation of hardwood and root cuttings makes it convenient to deal separately with each main type.

(*a*) **Hardwood cuttings**

Deep planting prevents desiccation but reduces aeration at the base of the cutting. Temperatures are more constant at greater depths and by deep planting a cutting is firmly fixed in position. Graham (1934) writes, "When cuttings are planted in open ground the insertion must be deep enough to avoid throwing out by frost."

Practical nurserymen find that in periods of alternating frost and thaw even very long cuttings are seriously lifted and must be pressed down again. Apparently the chief disadvantage of deep planting is the lack of aeration at the base of the cuttings. Laurie and Chadwick (1938) remark that though cuttings normally root at the basal end, showing strong polarity, they tend to root more at the surface of the medium where there is more air.

Garner (1943) describes the planting of plum cuttings vertically three-quarters of their length. He says that very deep planting of long cuttings makes lifting of rooted cuttings difficult, especially in soils not easily worked.

Baak (1938) recommends the use of poplar cuttings 15-18 cm. long, 5-10 mm. thick, planted upright with the top of the cutting beneath the soil. This deep planting secures rapid occlusion of the apical end and results in the production of a plant with a straight stem.

Casella (1931), working with olive, used short thick hardwood cuttings which were planted either horizontally or vertically 6-10 cm. below the surface. Resulting shoots were reduced to one whilst young. By slanting the cutting the depth of planting may be adjusted without exposing more of its length. Opsomer (1937) working in the Congo with cassava cuttings tried horizontal, vertical and oblique planting and all rooted well. He preferred oblique planting because, even if carelessly inverted by the unskilled planter, the cutting would make a fairly good plant. Bolhuis (1939) also using cassava found that planting inversely greatly reduced the yield of roots, and incidentally he proved that inversely planted cuttings were more poisonous, as was the native tradition.

In connection with angle of planting it may be noticed that Ducomet and Soutz (1937) stored 8 in. cuttings of peach (*P. persica*) horizontally in sand during the winter and planted them normally under cloches in the spring and had some success. Masot (1938) states that hardwood cuttings of most species will root better if they are first buried head downwards in sand. Lifted and planted normally they root quickly, having meanwhile callused freely, before the top growth has time to start. The treatment is to invert bundles of cuttings below 2 in. of sand, in a fairly warm situation, where they are kept moist.

Watkins (1940b) describes the use of " callusing pits " in the propagation of Florida ornamentals by hardwood cuttings. Dormant cuttings ten to eighteen inches long are bundled with bases level. A hole is dug, in well drained sandy soil in a sunny position, in which the bundles are placed inverted with their bases 10 in. below the surface of the soil. The cuttings are covered with sand. A shallow depression is left above the cuttings to gather water so that it may percolate through the bundles of cuttings. Heavy callusing takes place in three to eight weeks, the cuttings are then lifted and planted normally, care being taken to avoid drying.

(*b*) **Softwood cuttings**

Workers at the Royal Botanic Garden at Edinburgh, Bayley Balfour (1913), Stewart (1927), and Graham (1934) insist upon shallow planting. They say that the cutting should go no deeper than suffices to maintain it steadily in the soil. A dibber should not be used because of the danger of an air pocket between the base of the cutting and the rooting medium. Their rule is to hold the cutting between forefinger and thumb and press gently into the medium " just deep enough to make the cutting stand erect ". Watering levels the surface and does all necessary firming.

Shallow planting brings the base of the cutting into the best aerated part of the medium and Cayeux (1936) found that shallow planting reduces rotting of leaf-bud cuttings of dahlia.

In practice it is found that the good habit of retaining all leaves on softwood cuttings prevents deep planting, provided no leaf is buried. Hitchcock and Zimmerman (1932) describe some detailed experiments in which firm " slow growing " summer cuttings were planted deeply with success. The cuttings were set in sand or a mixture of peat moss and sand, without bottom heat, so that only a few leaves were exposed. Some or all of the leaves were left on the buried part. Water was added to settle the medium around the cuttings, and during the watering the tops were pressed with the palm of the hand, so that most of the exposed leaves lay close to or flat on the surface of the medium. A single layer of cheesecloth was laid on the top, watering being subsequently done over the cloth. During cloudy periods or in cool weather the cloth was removed, but it usually remained on the cuttings overnight during spring and summer.

The cloth was sprayed several times a day during hot weather. No lights were used either on frames outside or over the greenhouse benches.

(*c*) **Root cuttings**

It has been the general practice to plant root cuttings with the proximal end just below the surface of the medium. Recently some workers have obtained much better results with the proximal end above the medium. Halma (1931) records the severing of roots of established citrus and the raising of them above the surface of the soil. It appears that the roots of young trees respond fairly readily to this treatment but usually old trees do not. Potter (1936) and Stoutemyer, Maney and Pickett (1936) have laid root cuttings upon the surface of the medium as already described. Upshall (1936) using root cuttings of apple and plum varieties and a cherry (*P. avium*) rootstock had much better success with the proximal end above than below the surface. The cuttings were set on an open bench within a greenhouse. Not only was there a much better rooting response from the cuttings which projected above the medium, but top growth was much more rapid and the cuttings which failed to develop into new plants did not rot so quickly as those which were completely submerged.

Hilkenbäumer (1940) found that it was best to plant root cuttings of fruit tree rootstocks vertically and not on the slope.

3. MOISTURE, TEMPERATURE AND LIGHT

Blackman (1934) states that light, temperature, air humidity and soil humidity are all important in the growth of plants and *the alteration of any one of them will almost certainly affect the action of the others*. It is, therefore, appropriate to deal with these matters together. Sorauer (1895) writes that no general rules can be given as to the amount of light, moisture, air or heat necessary for cuttings, as the requirements of various plants differ so much. From what is now known about the variation in condition of cutting material when collected one could add nutritional differences within a variety as a further complication. Sorauer recognized that herbaceous cuttings require special treatment. "An herbaceous cutting is dependent for its food upon its leaves, it needs comparatively much light. It requires more heat than a woody cutting to stimulate rapid changes. Loss of water, without removing leaves, is reduced by a moist atmosphere and air is necessary at the base of the cutting to prevent harmful fermentation."

Bayley Balfour (1913) gives three rules governing the treatment of cuttings. (*a*) Maintain adequate water supply in the cutting until it is able to absorb for itself. (*b*) Apply stimuli to encourage the development of the new water-absorbing organs and to promote the development of the shoot. (*c*) Secure adequate temperature and aeration at the rooting end of the cutting.*

(*a*) **Hardwood cuttings**

The conditions required for hardwood cuttings and root cuttings have received far less attention than those for softwood cuttings and can be reviewed very briefly. Knight (1926) found that high water content of the medium favoured callusing but reduced rooting in hardwood cuttings. On the contrary Hunter (1932b) obtained indications that actual root formation, as distinct from callusing takes place under fairly wet conditions and he recommends increasing the water supply after callusing. Knight was working with deciduous hardwood and Hunter with leafy hardwood citrus cuttings. In general most hardwood cuttings are leafless, or nearly so, and therefore require less moisture than leafy softwood cuttings in which internal changes take place more rapidly. In countries having a temperate winter climate hardwood cuttings are made and planted in the open ground in early autumn and the conditions of moisture and temperature are governed by the local weather. Sometimes the cuttings are artificially watered or irrigated at the time of planting, if the weather is dry, and this may also be done in the early summer of the following year. In countries having severe winters hardwood cuttings are planted in the spring without special provision of water. The writer and his colleagues conducted a

* Aeration at the rooting end of the cutting has been considered under the headings of Medium and Depth of Planting.

small scale experiment with hardwood cuttings in the open ground under which hot water pipes were placed in an attempt to encourage early activity at the basal end of the cuttings. This proved unsuccessful. Laurie (1930) showed that a number of hardwood cuttings could be rooted in the spring by placing them horizontally in peat at a temperature of 65° F. Presumably the rooted cuttings were then transferred to more normal quarters and this special preliminary treatment could be regarded as a " treatment before planting ".

(*b*) **Softwood cuttings**

Many workers have studied the effect of moisture, heat and light upon the rooting of softwood cuttings.

It is generally recognized that maximum light, compatible with the avoidance of wilting or overheating, is essential for the best results. Knight and Witt (1927) using closed frames with bottom heat exposed the cuttings to full daylight as far as possible. Even so, careful shading is necessary in sunny weather. High humidity does not obviate the necessity for shading as Stoutemyer (1942) showed in his experiments with an electrically driven humidifier. Stoutemyer quotes Raines (1941) for evidence that prolonged washing of the foliage is undesirable and describes a practical method of maintaining a saturated atmosphere, in a greenhouse, with a very limited amount of water. A Walton centrifugal atomizer placed several feet above the medium in a greenhouse compartment 15 × 25 ft. kept the air saturated. Two pints of water per hour were required and the motor consumed $\frac{1}{4}$ K.W. in eight hours. The apparatus was in operation from 8 a.m. to 5 p.m., rather less on cloudy days. The ventilators were closed and the house shaded with slats. The temperature at times rose to 100° F. without damage to the foliage but attempts to reduce the shading caused injury.

Pinckard and Bozovaisky (1942) have overcome the connection of light with temperature by designing a small refrigerated plant culture chamber for the needs of small-scale greenhouse research. This chamber is for use in full sunlight between 65° and 105° F. and in darkness as low as 25° F. The principle of design may be described as the movement of low-velocity air at a stated temperature across surfaces exposed to light radiations.

Excellent work has been done in maintaining moisture merely by the use of the watering can or some simple method of irrigation.

Graham (1934) describing the methods used by Stewart says that cuttings in unheated frames were kept turgid by hourly syringing with water of the same temperature as the frame. In heated frames the ascending water vapour from the medium makes syringing unnecessary.

The Tanganyika Department of Agriculture (1938) describe the maintenance of humid conditions in frames used for *Coffea* cuttings. This consists in syringing twice a day, watering the glass cover and the installation of an overhead shade of hessian 9 ft. above the ground.

Pyke (1931) maintained a moist atmosphere by standing porous pots at 1 ft. apart in the frame with a layer of cloth, kept moist, over all.

The frequent attention necessitated by many methods has mothered the invention of auto-irrigators. Decker (1933) maintained a water table at a definite height in sand media " by means of two lines taken from a sealed reservoir located above the propagating bed. The height of the media above the water table determined the amount of moisture it contained ".

Withrow and Biebel (1936) describe a method of intermittent irrigation which lends itself to large scale application. The water or nutrient solution is pumped electrically from a submerged reservoir into the bottom of the tank holding the medium. The pump is switched off by the rise of liquid in the medium and this then flows back into the reservoir by gravity. The pump can be controlled at will by the installation of a time switch.

Tamai (1941) describes auto-irrigation by means of porous surfaces, in contact with the medium, kept moist by capillarity. In its simplest form it is a stack of bricks with its base in a tank of water. The medium is placed directly upon the layer of bricks through which the moisture rises from the store below.

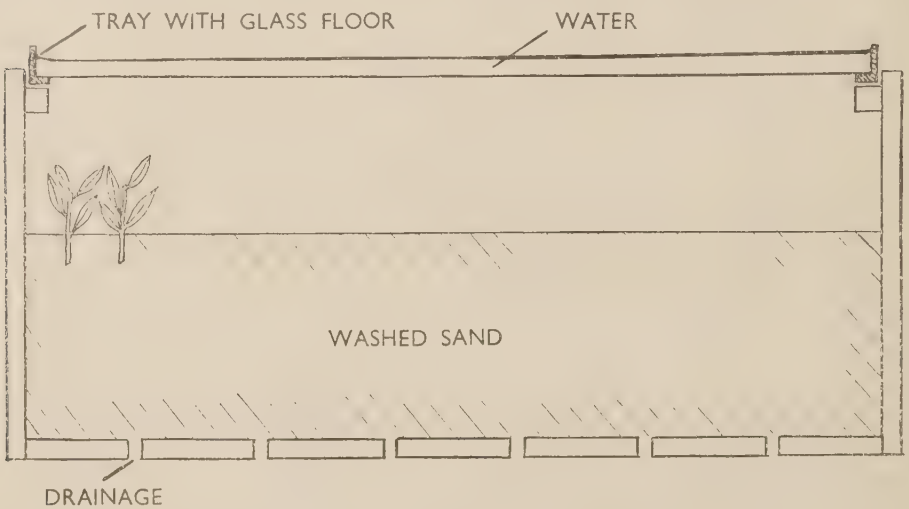
It is generally agreed that it is good to have the temperature at the basal end of the cutting somewhat higher than at the apex, hence the beneficial effect of bottom heat. In the distant past this was provided by the use of fermenting material, usually horse manure, or by various hot water systems and chimney flues. Nowadays more convenient devices are available,

the majority of which make use of electrical energy. Thermostatic control is necessary. Brown (1933) describes the use of electric heating cables for hot beds.

The majority of glass houses are heated by a system of hot water pipes and electrical heating is confined to individual frames. Bewley (1934) suggests that the heating of soil in glasshouses by means of hot water pipes is cheaper than electrical methods. In his experiments Bewley took hot water from the heating system of the house and by means of an electric pump forced it through 1 in. pipes spaced 18 in. apart 1 ft. below the soil surface. The pump was fitted with a starting device actuated by a soil thermostat, which regulated the circulation of hot water in the pipes in accordance with the soil temperature.

Hammer and Oehlkers (1942) describe a very economical method of heating small localized areas of soil. Small heating spirals are fitted in tubes 15 mm. in diameter and about 1 ft. in length. The ends of the tubes are pushed into the soil and the conduction wires are connected with each other and with the main supply. It is claimed that the soil is heated exactly where necessary, and nowhere else, with the minimum expenditure of electrical energy.

In climates of abundant sunshine direct use has been made of the sun's energy to provide bottom heat. The device is the solar propagator and was, apparently, first described by Westgate (1921) as being used in Hawaii. Swingle, Robinson and May (1926) detail improvements in design and report at length upon its use at Washington, D.C. Hunter (1931) describes a simple solar propagator used by him in Trinidad for trials with citrus cuttings. The apparatus consists of two compartments one for heating and the other for the medium and cuttings. The heating chamber, which is oblong in shape and covered with a glazed sash serves to trap the sun's rays. The air within this becomes much heated during the day, part of the chamber is beneath the medium and so provides bottom heat. The heating chamber is approximately double the size of the other. In it are placed a number of large stoppered glass bottles, painted black outside and filled with water. They serve to store heat by day and emit it by night, thus tending to keep the temperature uniformly high within the propagator.



Propagation case for use in the tropics.

Another method of keeping the temperature uniform was recently communicated to the author by Mr. J. Floor who used it in Dutch Guiana in 1938-39 for the propagation of citrus stem cuttings. A box having holes in the bottom for drainage was half filled with washed sand as shown in the diagram. The lid was a tray with a glass bottom and a raised metal edge in which there was about half an inch of water. The box was placed under a house verandah facing a river where it received maximum light other than direct sunlight. The whole apparatus

was covered with blankets at night and it was found that the temperature in the box varied very little throughout the twenty-four hours. Using vigorous shoots, from mature trees, with fully expanded leaves, Floor obtained 80-90% rooting with sour orange, lemon and citron, and some 60% with sweet orange. Tea cuttings rooted 20% some six months after planting but with this subject the rootgrowth was meagre.

The use of extra illumination has not been fully investigated. Laurie and Chadwick (1938) suggest that results with herbaceous cuttings indicate that possibilities lie in this direction. Skinner (1939) reports obtaining a 10% increase in the rooting of rhododendron leaf-bud cuttings taken in winter. Eighteen hours' additional light from electric bulbs providing 26± foot candles at the surface of the medium was compared with 10½ hours of daylight alone.

The quality of light has been studied in connection with the rooting of cuttings but in general results have been inconclusive or contradictory. Smith (1931) found no advantage in the use of ultra-violet ray glass. Tincker (1930) and (1932) had variable results. Both these workers studied intact plants and not cuttings, but the fact that Tincker obtained an increase in the root/shoot ratio by the use of " Vita " glass is of interest. Unfortunately the glass used varied in thickness and some temperature differences observed were thought to be largely due to this.

As Blackman (1934) states : " We may follow Popp and Brown (1933) in the conclusion that it has not been demonstrated that ultra-violet light is of importance to the growth of plants, and that any excess of such light rapidly causes injury. It does not follow from this reason that plants may not grow better under some of the special glasses which are more transparent to rays of short wave-length than ordinary glass. Any improvement observed may, however, be due to the fact that the glasses in question affect the transmission of rays other than the ultra-violet. It is evident that, for plants, there is no special ' magic ' in such light."

Jackson (1939) struck coffee cuttings under differently coloured light. Coloured cellophane placed between two sheets of glass was used, colourless cellophane being used as a control. Thirty-six clonal cuttings were treated with growth substance and were divided into four lots of nine. The cuttings were set on 2nd February and, at the same time, a seedling plant of *Carica candamarcensis* Hook f. was placed under each light, the height of each plant was 8 in. By 24th June the results were as in the table below.

Colour of cellophane.	No. of cuttings alive but unrooted.	No. of cuttings rooted.	No. of cuttings dead.	Growth of *Carica* plants.
Red ..	6	0	3	4 in.
Yellow ..	3	6	0	14 in.
Blue ..	8	0	1	10 in.
Control ..	7	2	0	2 in.

Jackson, writing at the time, said that the unrooted cuttings under the yellow light showed signs of rooting in the near future but was careful to state that further experiments were required to confirm this result.

Blackman (1934) discusses the effect of differing qualities and intensities of light upon plant growth. He points out that in general light has a retarding effect upon growth, and it is well known that weak light produces spindly plants and *vice versa*. This could account for the small increase in height of the control *Carica* plant in Jackson's table. Red light has little more effect than darkness. For assimilation of carbon dioxide red-orange light is the most potent. The exact qualities and intensities of the light transmitted by the coloured cellophane used is not stated but Jackson's early results would seem to be connected with carbohydrate formation, already shown to be correlated with rooting and the lower rate of rooting under the control might be due to excessive light, judging by the lack of growth in the *Carica* plant.

Zimmerman and Hitchcock (1929) found that length of day determined the type of root system formed by cuttings of dahlia, heavy root storage being correlated with a short

day and a fibrous system with a long day. Zimmerman and Hitchcock (1940) studying the formation of adventitious shoots and roots found that light was not a controlling factor for the formation of adventitious buds on mature stem tissue. *Althea* cuttings in the dark formed shoots as readily as cuttings in the light. For further development of the shoots light was, of course, necessary. When in light the callus of control cuttings developed chlorophyll but the callus of cuttings effectively treated with growth substances remained white in light, as did the roots of treated and untreated cuttings, suggesting some relationship between root tissue and callus stimulated with growth substances.

(*c*) **Root cuttings**

It is well known that root growth is seriously inhibited by light. Rogers (1939) using glass panels in root observation trenches found that continuous exposure to light severely checked the growth of roots and hastened suberization. Oinoue (1936a) studying the "transmutation" of stem into root and *vice versa* found that stems in moist and warm atmospheres in the dark developed roots whilst roots in somewhat drier conditions in the light developed shoots. Root cuttings are normally planted entirely below soil level. This is generally considered necessary to prevent drying as it is known that roots dry out more quickly than stems on exposure to air. This complete covering incidentally prevents access of light to the cutting. Upshall (1936) reports three years' work with root cuttings of apple and plum and one trial with cherry planted in a greenhouse with the proximal end above the medium. Such cuttings rooted much better than those normally planted and he attributed the success to the light factor or to a combination of water and aeration effect. Hilkenbäumer (1940) found a temperature of 17 to 20° C. better than 20 to 25° C. for root cuttings of apple, pear, plum, and cherry.

4. APPLICATION OF STIMULANTS

(*a*) **Nutrient solutions**

Schindler (1932) tested cuttings of deciduous fruit tree rootstocks in various culture media differing in their reaction. He obtained the best results with a complete culture solution rich in nitrogen, the action being practically neutral. The knowledge that nitrogen is essential for growth has led investigators to use nitrogen in excess as an aid to regeneration. Oinoue (1936b) sprayed root cuttings of Japanese persimmon with ammonium nitrate and obtained increased growth. Haas (1937) working with avocado cuttings sprinkled beds of callused cuttings about once a week with a complete culture solution rich in nitrogen and had good success. Grace (1939b), making weekly applications of Hoagland's solution to cuttings of Norway spruce, greatly increased the number rooted and their growth. The solution was reinforced with 120 p.p.m. sodium chloride, 1 p.p.m. boron, 0·44 p.p.m. manganese and 0·16 p.p.m. zinc.

Thimann and Poutasse (1941) studied root formation in leaf bud cuttings of *Phaseolus vulgaris* in solution culture. They found that a complete nutrient solution generally retarded root formation. This effect was in sharp contrast with the behaviour of the salts separately. Rooting was markedly inhibited by $MgSO_4$ and by $Ca(NO_3)_2$ at the same concentrations as in the nutrient solution, but was strongly promoted by KNO_3. The addition of organic nitrogen benefited rooting. Adenine gave the most consistent results. In one experiment 4% rooted in water controls and 42% treated with 50 mg. per litre. In another experiment 38% rooted in auxin-treated controls and 77% when auxin treatment was followed by treatment with adenine 200 mg. per litre. Pearse (1943) finds that response to additions of KNO_3 to the rooting medium was dependent upon the nutrition of the parent plant from which cuttings were taken. Thus :

> (1) Vine eye cuttings from plants grown under conditions of mineral starvation or semi-starvation, and exhibiting symptoms of nitrogen starvation, (*a*) bore small pale green leaves, and rooted readily ; (*b*) responded to the addition of a solution of KNO_3 to the rooting medium by an improvement in leaf size and colour and a diminution of root formation ; (*c*) responded well to treatment with indolyl-butyric acid, both number and length of the roots being increased ; (*d*) responded exceptionally well to a treatment with indolyl-butyric acid plus the addition of KNO_3 to the rooting

medium, leaf size and colour being improved and the number and length of the roots being very greatly increased.

(2) Cuttings from plants grown under conditions of adequate or excessive nutrition, and making very vigorous growth (*a*) bore large green leaves, and rooted very poorly ; (*b*) did not respond by improved root formation when KNO_3 was added to the rooting medium ; (*c*) responded poorly to treatment with indolyl-butyric acid, neither root number nor length being increased to an appreciable degree ; (*d*) did not respond by increased root formation to a treatment with indolyl-butyric acid plus the addition of potassium nitrate to the rooting medium, and moreover the mortality of the cuttings was increased by this treatment.

The fact that the addition of nitrogen benefits regeneration might lead one to suppose that liquid animal manure would have similar effects. This has not occurred in practice. It is reported by the Indian Tea Association (1942) that the admixture of cattle manure in the cutting beds or the subsequent watering of the cuttings before rooting with cattle manure water was detrimental.

(*b*) **Vitamin B_1**

Went, Bonner and Warner (1938) state that under normal conditions the extremely small amounts of vitamin B_1 required for root growth are supplied by other parts of the plant. They found that under certain conditions the absence of this substance is the limiting factor for rootgrowth and they obtained a higher proportion of rooted cuttings and increased rootgrowth by its use. The cuttings were pre-treated with auxin, planted for a week, and then lifted and placed with their bases in a solution of 1 mg. vitamin B_1 in a litre of water for twenty-four hours before replanting. Pearse (1939a) was unable to increase the percentage of cuttings rooted, although the rooted cuttings showed a tendency to grow more strongly after transplanting. Hitchcock and Zimmerman (1941) found that watering the cutting beds with a solution of vitamin B_1 only benefited species which did not produce sufficient of their own B_1 vitamin. Murneek (1941) obtained equally good results with a layer of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. of leaf mould on the surface of the medium of humus and soil. Murneek points out that the mulch of humus material lying on top of the medium was watered with water of high calcium content and he considers that this encouraged azotobacter development ; these bacteria synthesize large quantities of B_1 vitamin. Watkins (1940b), on the other hand, suggests that alkaline water will render vitamin B_1 ineffective and that it is necessary to use water that has a pH below seven.

(*c*) **CO_2**

Mauri and Mauri (1939) report accelerated rooting and increased top-growth by the use of CO_2. The frames were closed in the mornings and a $3 \cdot 5\%$ concentration of CO_2 administered. The frames were open during the night. Used in conjunction with auxins the results were even better.

(*d*) **Light**

Moshkov and Kocherzhenko (1939) working with *Salix* species came to the conclusion that light conditions are very important. Generally speaking, the best method of preparing material is to grow the plant under optimum light conditions for its life activity but, at the actual time when root formation is required, it is best induced by continuous illumination. Pratt (1940) using *Coffea* cuttings found that those set under yellow glass rooted better than those under clear, blue, green or red glass (*see also* Jackson (1939), page 37).

(*e*) **Synthetic growth substances**

The watering or spraying of cuttings with growth substances has not apparently been reported as successful. Milbrath and Hartman (1940) sprayed holly sprigs with α-naphthaleneacetic acid to retain the leaves for ornamental purposes. Those sprayed with $\cdot 005\%$ solution retained their leaves eight days, those with $\cdot 01\%$ solution fourteen days. The latter finally rotted without dropping their leaves. The authors therefore suggest that some milder treatment

might prove useful for retaining leaves on cuttings. Myers (1940) tested the effect of growth substances on the formation of the abscise layer in *Coleus* and found that treating debladed petioles with growth substance dissolved in anhydrous lanolin delayed abscission.

(*f*) **Sphagnum moss**

Watkins (1940b) found that a thin layer of live sphagnum moss placed on the leaves of citrus cuttings prevented curling and leaf drop. The cuttings rooted more quickly and the leaves remained green.

(*g*) **Disinfectants**

Cuttings set in closed frames with high temperature and moisture are prone to succumb to diseases which flourish in such conditions. Gillett and Jackson (1937) found that watering cuttings of *Coffea arabica* in East Africa with dilute Cheshunt Compound* proved beneficial in preventing bacterial and fungal infection of the cuttings. Grace (1939b) killed fungal growths on cuttings of Norway spruce with 2 p.p.m. ethyl mercuric bromide solution given twice with a three-day interval. Neither of these treatments harmed the cuttings. Cooley (1942) found that a reliable method of combating *Rhizoctonia* infection in holly cutting beds was the removal of the sand and its replacement with clean sand after washing the bench with disinfectant.

(*h*) **Oxidizing agents**

Curtis (1918) treated *Ligustrum ovalifolium* cuttings with potassium permanganate solution prior to planting and obtained marked increase in rooting. One of the successful treatments was standing the cuttings in a 1% solution for twenty-four hours before planting in sand. Curtis suggested various causes for this effect the most likely being the increase in respiratory activity due to catalytically hastening oxidation. Laurie and Chadwick (1938), reporting earlier work of Chadwick, recommend the watering of the medium some twenty-four hours before inserting the cuttings. The medium is thoroughly wetted with a solution containing 1 lb. potassium permanganate to 50 gallons water. About $\frac{1}{2}$ gallon is required for each square foot of medium. No further watering is required before planting.

Klein (1931) treated cuttings of conifers with sugar solutions and with ·01 M. potassium permanganate ; ·0001 M. manganese sulphate and ·05 M. hydrogen peroxide. In all cases potassium permanganate produced the best results, but Klein considers it doubtful if any of these treatments is of commercial value.

SUMMARY

1. Good aeration is the first essential in a medium but it must be accompanied by moisture. The presence of appreciable amounts of nitrogenous material is harmful to rooting and media which encourage the growth of organisms causing rotting are to be avoided. Peat and certain other materials may provide rooting stimulants of growth substance nature.

2. Depth of planting affects conditions at the base of the cutting. Hardwood cuttings are planted deeply in well aerated soils to fix them in position and to provide uniform moisture at their base. Softwood cuttings are planted fleetly in well-aerated media in propagating cases supplied with ample moisture. Stem cuttings, inverted for a time, callus freely and root better on planting than cuttings never so inverted.

The behaviour of root cuttings is sometimes improved by planting with the proximal end above the medium.

3. Experiments, chiefly with softwood cuttings, have been concerned with the effect of moisture, temperature and light upon planted cuttings. Deciduous hardwood cuttings callus better in very moist conditions but require good aeration for rooting. Softwood cuttings require much light ; bottom heat and moisture must be provided to correspond.

* Cheshunt compound. Mix 2 oz. finely-ground copper sulphate with 11 oz. ammonium carbonate Store in a tightly corked glass or stone jar for not less than 24 hours. The solution is prepared by dissolving 1 oz. in a little hot water and adding water to make up to 2 gallons.

Light of special wavelengths has not proved an advantage, but there is some evidence that an increased period of illumination is beneficial.

Root cuttings require adequate moisture to prevent desiccation.

4. Nutrient solutions, containing excess of nitrogen, sometimes stimulate rooting. Cuttings from plants partly starved of minerals, exhibiting nitrogen starvation, have responded, but not cuttings from vigorously growing plants.

Varying results have come from treatment of planted cuttings with synthetic growth substances. Adding CO_2 to the surrounding atmosphere, watering with disinfectants, oxidizing agents and sugars, and the placing of a thin layer of live sphagnum moss upon leafy cuttings, have in some cases proved beneficial.

PROPAGATION BY LAYERS

The term layering is used to cover all processes in which a part of the plant, usually the stem, is induced to grow roots and/or shoots before separation from the parent. Thus the term covers stooling, layering, and all types of marcottage or gootee, and it is convenient to deal with subdivisions individually.

A. STOOLING

This is the simplest method of layering. The parent plant having first become established is cut down to the ground and resulting growths from the stub or stool are earthed up. Knight and others (1927) describe the method and point out that the greatest number of new shoots is obtained when the crown of the stool is exposed to light and air, but shoots emerging under these circumstances do not develop roots so well as shoots which have arisen from a stool lightly covered with soil. In free rooting varieties the stool is not covered with soil but with shy rooting subjects the authors suggest lightly covering with soil before bud break.

Cannon (1941) was unable to find any correlation between size and position of shoots on an established stool. In so simple an operation there is little room for varying the technique; this doubtless explains the few references to this operation. Garner (1943) advocates that the mother plant should be cut down by means of a knife and not by shears as these latter bruise the tissues and hinder new shoot growth, and he advises that all pruning of stools should be carried out whilst the plant is dormant. Tukey and Brase (1934) report the winter killing of quince stools which they considered due to the removal of shoots the previous autumn whilst in full leaf. At East Malling Research Station Modlibowska and Field (1942) found that unearthed quince stools, from which the crop was removed, were killed in a severe winter whereas adjacent unharvested rows were not damaged.

De Wet (1937) describing propagation of fruit tree rootstocks in South Africa suggests the coating of uncovered stools with lime wash to prevent damage during occasional hot dry spells during the dormant season.

Tukey and Brase (1930) found that the addition of granulated peat moss to stoolbeds of apple and quince materially increased the quantity and quality of rooting. The dressing amounted to 52 bales per acre. The bales were broken in a truck and thoroughly wetted with water before spreading. Dry peat was found to blow about badly and was difficult to work into the soil.

Lange (1942) recorded the moisture and temperature of soil around mounded stool shoots of apple rootstocks in relation to the initiation and growth of roots. Root initials were first found in most varieties at the end of May or early June and continued to appear up to the middle of July. The development of root initials was dependent on soil temperature and soil humidity. From June till August the temperature is generally adequate and root development is dependent upon moisture. The cessation of root development in September is primarily due to the temperature. Lange suggests that practical improvements can be made by increasing the water holding capacity of the soil and by further studying the optimum time for earthing each variety.

B. LAYERING

Layering is not so simple as stooling and is, therefore, usually reserved for comparatively shy rooters. Knight and others (1927) state that these shy rooters do not root readily on severely pruned stools, even if the bases of the shoot are etiolated by pre-earthing. In order to obtain a reasonable crop it is necessary to take advantage of the buds upon one-year-old shoots which have been laid horizontally.

1. ETIOLATION METHOD

The layering method developed and practised with success at East Malling has been described by Knight and others (1927) and Garner (1943). Feilden and Garner (1940) term it the Etiolation Method and briefly describe it as follows: "Young plants of the variety to be layered are set (Fig. 5 A) at an angle of 45 degrees in rows 5 feet apart. The distance between the rows is designed to allow for the future drawing up of enough soil from between the rows to cover the layer beds to a depth of 6 inches. The plants in the rows are spaced so that they will form a continuous line of shoots when laid down. When the plants are well established (an important point), they are pegged down flat in shallow trenches along the rows. With deciduous trees this is done in the dormant season. Immediately before bud break the whole plant is covered with fine soil to the depth of one or two inches only in the first instance and more earth is added as the shoots push up, until the bases of the shoots are covered to a depth of from 3-4 inches, the mound finally reaching a height of 6-8 inches around the stem. The lower part of the shoot is thus always kept in the dark and so becomes etiolated. In the case of many subjects this blanched portion will put out roots with more or less freedom according to the variety. At the end of the growing season the rooted shoots are removed and planted out, sufficient numbers being left on the parent plant to form future layers. Thus the bed once established becomes more or less permanent and a constant supply of young plants can be obtained. This, briefly, is the method adopted in raising rootstocks of certain deciduous fruit trees at East Malling. It can, of course, equally well be applied to trees which it is desired to establish on their own roots."

Thomas (1938) found it inadvisable to use freshly cut timber for stakes in pegging down the layered shoots as the fungus *Armillaria mellea* was introduced and he therefore used wire pegs throughout.

Sinha (1942), working with a ten-year-old layer bed, found that reduction in length of the laid, or parent, shoots markedly increased rooting as did removal of buds from the upper sides of the laid shoots; both reduction of shoot length and removal of buds increased the output of rooted layers. Thus, shoots arising from the undersides of the layer rooted best. They were etiolated over a greater length and also had a bend at their base.

2. CONSTRICTION BY WIRING

Many workers have found that constricting the base of new shoots by wiring increases rooting.

Höstermann (1930) was successful in rooting stone and pome fruits, including their rootstocks, and many other plants such as mulberry (*Morus nigra*) laburnum and elm (*Ulmus*). The mother plant is cut down close to ground level in the autumn or early spring and the resulting shoots are wired at their base before the end of June and whilst secondary thickening is still going on. Thin pliable copper wire is used in three or four turns around the shoot taking care not to bruise or cut the bark. Not more than two-thirds of the shoots are wired so that the parent plant has the benefit of the remaining third. The wired shoots are then covered with soil in which is incorporated peat or similar material and further earthings raise the soil some four or five inches above the wire. Further thickening of the wired shoots brings about constriction and rooting takes place just above the wire.

Höstermann describes the budding or grafting of wired shoots whilst they are still attached to the parent plant and suggests that this saves taking up further space in the nursery required for planting out the rootstock.

Oppenheim (1932) used Höstermann's method with citrus in Palestine with considerable success. Hunter (1932b) rooted Kusai lime and grapefruit but the few attempts to root sour orange were unsuccessful. Luckan (1941) tried the method with the difficult rooting walnut with some success. Wellensiek (1932) working with tea (*Thea sinensis*) found that wired shoots denuded of leaves failed to root until the leaves were allowed to grow.

3. OTHER METHODS OF LAYERING

Many methods of layering ready rooting subjects are described in nursery textbooks. Chief among these are so-called simple-layering, serpentine layering and tip-layering.

(*a*) Simple layering

This consists in bending down a shoot and burying a part of it so that the tip is in the air. The buried portion is sometimes wounded by cutting in various ways or by twisting. The simplest method of cutting is by a single stroke upwards on the underside of the shoot to be buried. This cut may extend more than half-way through the shoot. The upward bending in the burying process opens the cut and the entry of soil prevents the cut surfaces growing together. With the cut underneath, the upward bending sometimes extends the cut by breakage and, therefore, some operators cut the upper side and give a sideways twist in bending the shoot upwards. This modification prevents breakages and completely separates the cut surfaces. Such layered branches are held firmly in position by pegs or a large stone.

(*b*) Serpentine layering

Long shoots are bent in an undulating way, alternately covered and exposed, thus a number of rooted layers may be obtained from one shoot.

(*c*) Tip layering

Here the apical ends of shoots are buried in the soil. The blackberry (*Rubus fruticosus* L.) and its hybrids are readily propagated in this way. Beakbane (1939) describes a method where nursery beds are established for propagation purposes only. The parent plants are set out 12 ft. apart each way and are cut back to 9 in. They are de-blossomed every year to prevent seedlings occurring among the tip plants. The soil is kept well cultivated until the first canes are long enough to be bent over and their tips buried in the soil. A hole is made about 6 in. deep with one side vertical and one sloping slightly towards the plant. The tip is placed in the hole with the cane lying along the sloping side and soil is pressed firmly against it. Layering begins early in July in England and continues till August, each shoot being layered when it is long enough to bend to the ground.

4. COVERING

Hatton (1921) and those associated with him, have stressed the importance of the early covering of layers (see Etiolation method). Ochse (1931) using the etiolation method in Java found it essential to prevent the washing away of the covering soil and also to cover the layered parent with an inch of soil before the buds grew out. On the other hand Lambourne (1934) working in Malaya found it a mistake to cover the buds with soil before they begin to grow as this treatment proved fatal to the evergreen trees of the tropics. He preferred to make a first earthing when the new shoots were four to six inches high, earthing them half their height. Thomas (1938), when layering scion varieties of apple in Queensland, found that young shoots, notably Delicious, Granny Smith and Frampton, were susceptible to heat injury. At ground level all tissue external to the xylem were killed and the shoots wilted and died. To prevent this it was found necessary to break up the surface soil around the shoots, especially the hard crust formed after rain, or to spread a thin coating of loose soil around the shoots.

Luckan (1942) conducted root box trials with pears and quinces and concluded that very much the most satisfactory root formation occurs when the medium is of a sandy nature well provided with organic matter.

5. USE OF GROWTH SUBSTANCES [*see* also under Marcotting]

Gossard (1940) produced roots on pecan stems both in trench and air layering in conjunction with indolyl-butyric acid by the toothpick method of Romberg and Smith (1939). Gossard obtained the best rooting on stems that were layered several weeks prior to treatment and considered that the right conditions for root production are a combination of etiolation, moisture, medium and growth substance.

Sinha (1942) temporarily uncovered earthed layers of plum and pear rootstocks, introduced lanolin containing indolyl-butyric acid into incisions and re-earthed. This treatment increased the rooting of the ready rooting Myrobalan B (a selection of *P. cerasifera*) but had no effect on the shy rooting Pershore (*P. domestica*) or the pear Malling C8 (*Pyrus cordata*).

C. MARCOTTING

This method is variously known as air layering, circumposition or gootee. Feilden and Garner (1940) describe marcotting as follows : " The selected branch is first girdled at the point at which roots are required, a strip of bark about an inch wide being removed. The girdled part is then, either immediately or in a day or so after the formation of a callus, packed with a ball of some rooting compost which may, for instance, consist of a mixture of soil, leaf mould, well rotted cow manure and sand with an outer wrapping of sphagnum moss or other moisture-holding material bound over the whole. In countries where there is a sufficient rainfall the rooting medium will be kept sufficiently moist ; failing that, it must be watered at intervals. An ingenious method of securing a continuous supply of moisture without much trouble is that in which a bamboo joint containing water is suspended above the marcot. From a hole in the bottom of the joint issues a string which is attached to the bandage, and thus by a slow but continuous percolation of water along the string the marcot is kept moist."

Hunter (1932b) states that marcottage is probably the most certain method of propagating woody plants. He was successful in rooting most species of citrus and he writes : " In the early experiments the region of the stem which had been ring-barked was covered with grit and sand or bound up with coconut fibre and watered every day. With both these treatments a very large callus tissue developed from the upper edge of the ring-bark but no roots were formed. Paring the callus had no beneficial effect. Finally, success was achieved by using damp moss with which to bind up the ring-bark. The moss " ball " so formed was surrounded on the outside with a sheet of rubber cut from old automobile tyre tubes and tied on somewhat funnel-wise. Water was given every day and the rubber efficiently prevented the moss from drying out between waterings." Hunter reports that the position of the wound in relation to buds is quite immaterial as the roots spring from the callus tissue and not from preformed root initials, and the size of the branches or the number of cycles of growth also has little effect. Roots appeared from 20 to 50 days after marcotting. Hunter stresses the importance in ringing of removing all tissue external to the xylem. San Pedro (1935) working with avocado in the Philippines found that the ringed bark callused very quickly and no rooting occurred. By removing the lower portion of the callus so that the ring was reopened roots grew strongly from the upper portion of the callus. A broader ring originally may have induced rooting.

USE OF GROWTH SUBSTANCES

Gossard (1940) obtained abundant rooting of pecan marcots as follows. The shoots to be marcotted received either a wrapping of tape, as used by Gardner for etiolating cuttings, or a marcot box. Some weeks later these coverings were removed and a toothpick impregnated with indolyl-butyric acid was inserted through the stem at the marcot position, before covering with moist material.

Thakurta and Dutt (1941) report that the application of 3% indolyl-acetic acid to the ringed portion of marcots when wrapping proved a successful method of rooting mangoes in India when the parent plants were two to three years old.

SUMMARY

Stooling, the simplest form of layering, is an efficient method for subjects which root readily. The etiolation method results in the formation of roots on subjects which are more difficult to propagate.

Simple-, serpentine- and tip-layering have their special uses. Wiring layers increases rooting above the constriction.

The success of air layers (marcots) chiefly depends upon thorough ringing and the provision of a constant supply of moisture.

Treatment with synthetic growth substances has, in some cases, improved the rooting of etiolated layers and marcots.

OTHER METHODS OF PROPAGATION

A. DIVISION

Propagation by division properly belongs to herbaceous perennials, but it also has its uses in the multiplication of woody plants. Stools and clusters of suckers of fruit tree rootstocks may be lifted and divided longitudinally so that the separate pieces each possess both root and shoot.

Feilden and Garner (1940) list division as a method of propagating various tropical and subtropical economic plants.

B. POLYEMBRYONY

The occurrence of more than one embryo within the seed has been recognized for some 200 years. The possibility of exploiting polyembryony as a means of vegetative propagation has been discussed by various workers and the practical aspects have been summed up in relation to citrus propagation by the Imperial Bureau of Horticulture and Plantation Crops (1932). Essentially the reliability of the method as a means of vegetative propagation hangs upon the recognition and elimination of the seedlings produced from sexual embryos. Unless this is completely successful polyembryony cannot be considered as a safe method of vegetative propagation.

C. TWINNING

Identical pairs of plants can be obtained by splitting seedlings immediately stem and root are clearly discernible. Loomis (1942) describes the twinning of *Hevea* seedlings. In one technique, known as the Ramaer method, the seedlings are split into two more or less equal parts by a vertical cut passing through the main stem sprout and taproot and between the cotyledon petioles. Thus each section remains attached to the seed by one of the cotyledon petioles. Another technique known as the Gambar method is considered superior. In this the vertical cut enters obliquely slightly above the axil formed by one of the cotyledon petioles with the main stem and proceeds downwards as before. The result is two unequal sections each attached to a cotyledon petiole. After splitting, the young plants are dependent on the cotyledons for about two weeks.

THE PRACTICAL APPLICATION OF RESEARCH FINDINGS AND METHODS USED AT EAST MALLING RESEARCH STATION

Compared with the ancient practice of vegetative propagation the science of physiology is very new and it is, therefore, not surprising that many physiological studies have done little more than explain the reasons for traditional practices. Nevertheless the discovery of the reasons for these practices has made possible the establishment of some general rules. The development of the use of growth controlling hormones is an outstanding contribution of science to practice. The ancient propagators were intuitively groping for these substances in the almost mythical employment of hare's blood as a dip treatment of cuttings and grafts and also in the use of germinating seeds as an aid to regeneration of plant parts.

Present day methods of propagation are a mixture of tradition reinforced and supplemented by knowledge recently acquired as a result of scientifically planned experiments. Some general guiding principles are followed, but each subject must be handled as best suits its individual characteristics and is most apt to produce the type of plant required. A description of the methods of propagation in use in one locality may well serve as a vehicle for conveying general principles. Propagators in other areas may find such a description useful but will certainly find it necessary to modify the technique to suit their local conditions and requirements.

With this preliminary caution the chief methods of vegetative propagation in constant use at the East Malling Research Station are here described. They are hardwood, softwood, leaf-bud and root cuttings, and the three layering methods, namely by etiolation, stooling and tip-layering.

A. HARDWOOD CUTTINGS

1. VARIETIES

In addition to currants and gooseberries certain fruit tree rootstocks are raised by hardwood cuttings, notably the Marianna, Myrobalan B, Brompton and Common Mussel plums and also various quinces. The method used for the plum rootstock Myrobalan B is described below.

2. SOURCE OF MATERIAL

At the end of the growing season, usually October, one-year shoots are collected from hedges, recently budded plants or from layer beds. Also the upper parts of layer-bed shoots are used, provided sufficient shoot is retained on the rooted layer. Shoots from established hedges are preferred.

3. HANDLING PRIOR TO PLANTING

The shoots retain most of their leaves and quickly " heat " if tied in bundles for more than a very few hours, therefore the shoots are not bundled for longer than necessary to convey them to the place where they are made into cuttings. The shoots are cut into twelve to fifteen-inch lengths, except for the tip of the shoot which is discarded as being too soft to make a good cutting. The rooted cuttings are used for budding or grafting and a relatively long cutting is necessary to bear both shoots and roots and yet leave sufficient space for budding on the original cutting when rooted and transplanted. No consideration is given to the position of the cuts in relation to buds. It is convenient to cut four or five shoots at once with a single stroke of

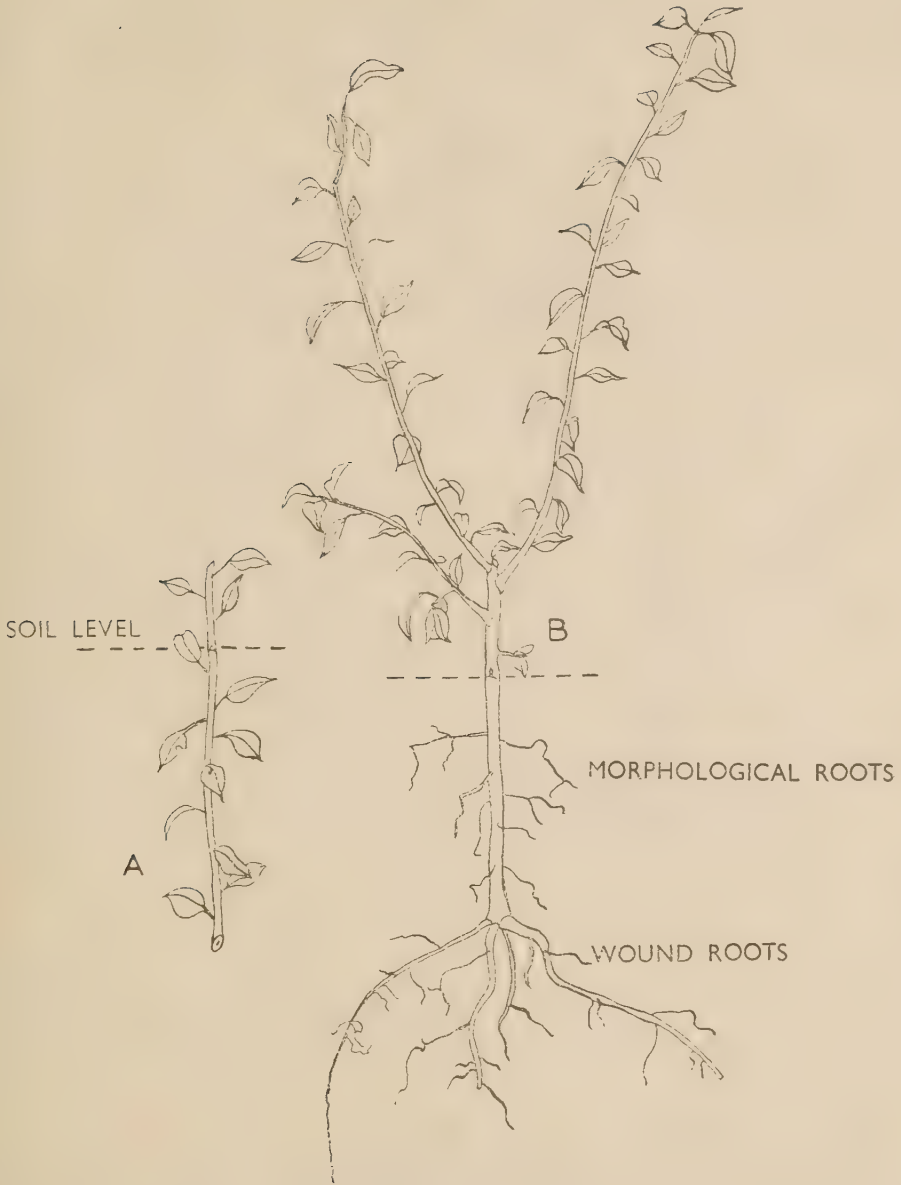


FIG. 1.

Hardwood cutting of Myrobalan B (*Prunus cerasifera*).

A. Cutting as planted.

B. The same one year later.

the knife. Some of the leaves, particularly on cuttings from the base of the shoot, are dislodged in the handling but reasonable care is taken to avoid undue loss of leaves.

The cuttings are planted immediately, but, should planting be interrupted, the cuttings are laid loosely in boxes and sprayed with water. For periods of delay of more than twenty-four hours the cuttings are heeled-in thinly in a moist situation.

4. PLANTING AND SUBSEQUENT TREATMENT

The cuttings are planted in open fields in normal medium loam soil. Soils known to be exceptionally shallow and dry are avoided. The distance between rows of cuttings is governed by the form of cultivation envisaged. In large beds cultivated by horse drawn implements the distance is 27 in. In small beds under hand cultivation 15 in. is found to be sufficient. The cuttings are planted about 2 in. apart in the rows. In cuttings of bush fruits they are spaced 6 or more inches apart in the rows to permit the growth of larger specimens but, in rootstocks, large coarse plants are almost useless and therefore close planting is the rule. The cuttings are planted vertically with some three-quarters of their length under ground. A spade is thrust into the soil to make a " grip ", or cleft into which the cuttings are inserted. The cuttings are made as firm as possible at their base by treading. This treading is regarded as very important and is done with the heel of the boot. The leg is kept rigid throughout its length and the whole weight of the body is brought down on to the heel every few inches along one side of the row in the direction of the base of the cutting. If this treading is well done the planting is completed by levelling off the soil, otherwise another treading is given after returning more soil and before finally levelling off.

Cuttings are planted in soil moistened by recent rains but should dry weather follow the planting the cutting bed is irrigated by overhead sprinkler or, on a smaller scale, by watering cans.

Surface cultivations are maintained up to severe winter frosts and again in the early spring and throughout the summer. May and June are regarded as critical months and special attention is paid to cultivation and in dry seasons the beds are heavily watered.

In July the lower young shoots arising on the cuttings are removed in order to clear as much of the stem as possible. When the leaves fall, the rooted cuttings are lifted, trimmed and graded. A stand of 50% well-rooted plants is considered quite satisfactory with the plum rootstock Myrobalan B, but most bush fruit cuttings root much better than this. Practically all one-year rooted hardwood cuttings are fit to line-out for budding the following season.

Hardwood cuttings exhibit two very different types of root on the same cutting. There are the wound roots at the base which are first produced and later, when the cutting has been set some months, morphological roots arise (see Fig. 1).

B. SOFTWOOD CUTTINGS

1. VARIETIES

Plum, cherry and pear rootstocks may be raised by softwood cuttings under carefully controlled conditions. Scion varieties are occasionally obtained on their own roots in this way for experimental purposes. Mahaleb and some of the acid cherry rootstocks are fairly readily raised by softwood cuttings. The propagation of the selected acid cherry East Malling F18/5 is here described.

2. SOURCE OF MATERIAL

Cuttings taken early in the growing season are superior to late cuttings for the practical reason that the rooted cutting has time to become thoroughly established before the winter. Lateral shoots not in active growth are preferred and it is found that these two conditions are opposed in plants established in the open ground, which continue to make rapid growth far into the summer. For this reason shoots produced from vigorous layers and from winter pruned plants, being comparatively succulent, are unsuitable for use as cuttings. The ideal material, being early and yet firm, is produced in bushy stock plants established some years in pots and brought into a warm house in late winter. These provide in May and early June excellent

FIG. 2.

Softwood cutting of acid cherry (*Prunus cerasus*).

A. Cutting as planted.

B. Cutting rooted after treatment with β-indolyl-butyric acid in talc. Note damage at base of cutting below the roots.

C. Typical roots on cuttings not-treated.

cuttings which root quickly and are fit to transfer to the open ground by early July. Unfortunately stock plants in pots require considerable labour in maintenance and occupy space in the house, thus they can only be provided for special subjects and the majority of soft-wood cuttings are collected from open ground plants. Established bushes with numerous lateral shoots are kept to provide cuttings.

3. HANDLING PRIOR TO PLANTING

Terminal shoots some three inches in length are collected and placed in baskets lined with moist sphagnum moss. In the propagation house the bases are cut internodally. Careful cutting when collecting makes this second cut unnecessary. No leaves are removed. In recent years various hormone treatments have been employed, the most common being talc dust containing β-indolyl-butyric acid at various concentrations.

4. PLANTING AND SUBSEQUENT TREATMENT

The cuttings are planted in quartz sand (from Leighton Buzzard, Bedfordshire) in closed cases with bottom heat. Some cases are heated by hot water pipes and some by electric cables thermostatically controlled at the temperature required. Usually a bottom heat of 75° F. is employed.

The sand is levelled off and then smoothed by watering. All water is obtained from a tank within the house so that it is warmed before use and does not seriously reduce the temperature of the medium, as it would if used direct from the main supply. The cuttings are set upright just deep enough to prevent them falling over when watered. No dibbers are used, except when dust treatment has been given, and each row is watered in from the side along the surface of the sand so that it is firmed about the base of the cutting. The distance between the cuttings is governed by the size of the foliage. Two inches between the cuttings and three inches between the rows is usually adequate spacing.

Watering and light shading is applied as necessary to keep the cuttings turgid. Any rotting leaves are removed as they occur and the lights are wiped free of condensed moisture each morning.

Rooting often begins some ten days after planting and in twenty days the bulk of the cuttings are fit to pot into clean dry two-inch pots. The potting mixture is made of equal parts of fibrous loam and sand. A little old rotted dung is placed in the bottom of the pot at the time of potting. Both pots and compost are stood in the house overnight to take on the local temperature before use.

The rooted cutting is placed at the side of the pot and the compost gently firmed against it. This procedure lessens risk of damage to the roots and probably assists root development by good aeration through the pot.

The potted cuttings are replaced in the case, or in a case at a similar temperature. In a few days air is admitted and the potted cuttings gradually pass to the open bench, thence to unheated frames in the open and, finally, into nursery rows where they are planted four to six inches apart. The next season they grow large enough to line out for budding, two years after setting in the cutting bed.

A typical cutting before and after rooting is seen in Fig. 2.

C. LEAF-BUD CUTTINGS

1. VARIETIES

Members of the *Rubus* family, which propagate naturally by tip rooting of the current season's shoots, are often readily multiplied by leaf-bud cuttings. The black raspberry roots readily when tip-layered and also as leaf-bud cuttings, but the red raspberry, which does not tip-layer, has not responded to attempts to propagate it by leaf-bud cuttings.

The hybrid berries such as the loganberry, boysenberry, youngberry, their thornless variants and many blackberries are fairly readily multiplied by leaf-bud cuttings. The loganberry serves as an example.

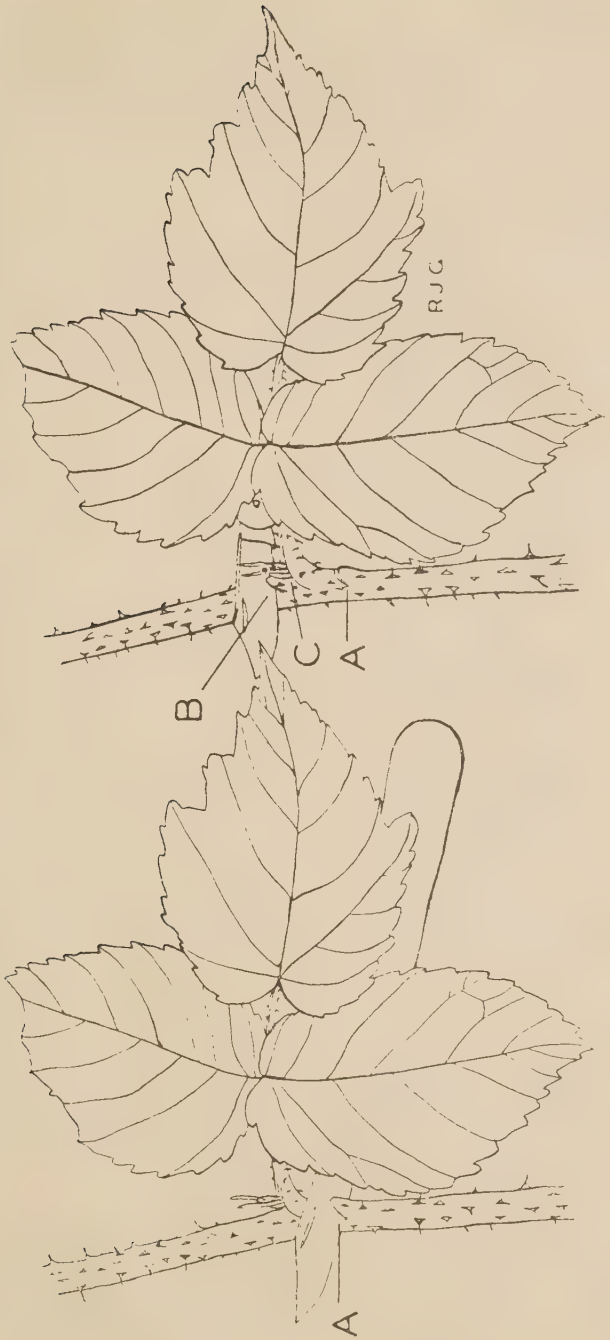


Fig. 3.
Propagation of a leaf-bud cutting of loganberry.

2. SOURCE OF MATERIAL

Only the current season's vegetative shoots provide suitable material; leaves from fruiting laterals generally merely develop further fruiting laterals. One or two shoots are collected during July and August from either fruiting plants or from transplanted tips in the nursery row, care being taken to avoid seriously depleting the new growth of the plant. Each shoot bears ten to twenty " leaf-buds " according to variety and growth. The shoots are kept moist until the cuttings are made.

3. HANDLING PRIOR TO PLANTING

All the leaves are used except the small unexpanded ones at the tip. The shoot is held by the lower end and a shallow cut (A) is made half an inch below the leaf as in Fig. 3. The knife is removed and a second cut (B), beginning half an inch above the leaf passes under the bud (C) to meet the first cut (A). This second cut should not penetrate the pith but should pass parallel with the surface through the solid wood-cylinder surrounding the pith. The cuttings are allowed to fall into a suitably placed receptacle, containing damp material to prevent them drying before they are set in the frame.

4. PLANTING AND SUBSEQUENT TREATMENT

The cuttings are generally planted in unheated frames placed on open ground into which some sand and humus material has been dug. The use of bottom heat in closed cases increases the speed of rooting but adds to the labour. The propagating cases described for use with soft-wood cuttings are sometimes used for leaf-bud cuttings, but more use is made of open ground portable frames as the cuttings may be left in position until transferred to the nursery row.

The cuttings should be planted as quickly as possible after preparation. The size of the foliage determines the spacing, but 2 in. $\times$ 5 in. is usual. The base of the cutting is set so that the bud and small portion of stem attached to it is just below the surface of the medium and the upper surface of the leaf exposed to the light. When each frame is filled a pit light is placed upon it and shading as necessary to prevent the leaves curling. Wilting is prevented by attention to shading and watering. Overwatering results in rotting of the cuttings and must be avoided.

Rooting, without bottom heat, is comparatively slow, and the frames remain completely closed for four or five weeks until roots have formed and ventilation can be given. The pit light is gradually raised until it is finally removed some two months after setting the cuttings.

Cuttings are left in open ground frames until the following March when they are transplanted to nursery rows for growing on. Cuttings rooted in heated propagation cases are boxed or potted and transferred to the open ground before the winter begins.

With forty to fifty per cent. rooting, in unheated frames, the operation is worth while. With some varieties, such as the youngberry, seventy to eighty per cent. rooting is not unusual.

D. ROOT CUTTINGS

1. VARIETIES

Many fruit tree rootstocks may be propagated by root cuttings, but the method is almost completely confined to plum rootstocks such as the Common Mussel (*P. insititia*) and others of the same type. Apple, pear and both sweet and acid cherry rootstocks are occasionally raised by root cuttings, but the Common Mussel provides the best example in England where some hundreds of thousand root cuttings are planted each year.

2. SOURCE OF MATERIAL

Roots from young trees not more than three or four years old provide the most suitable material for root cuttings. The usual source is the roots trimmed from trees lifted for replanting and sale by nurserymen. Thus root cuttings are a by-product of the tree nursery and provide an excellent example of the ideal source of material compared with the setting aside of stock plants solely for the provision of cuttings or layers.

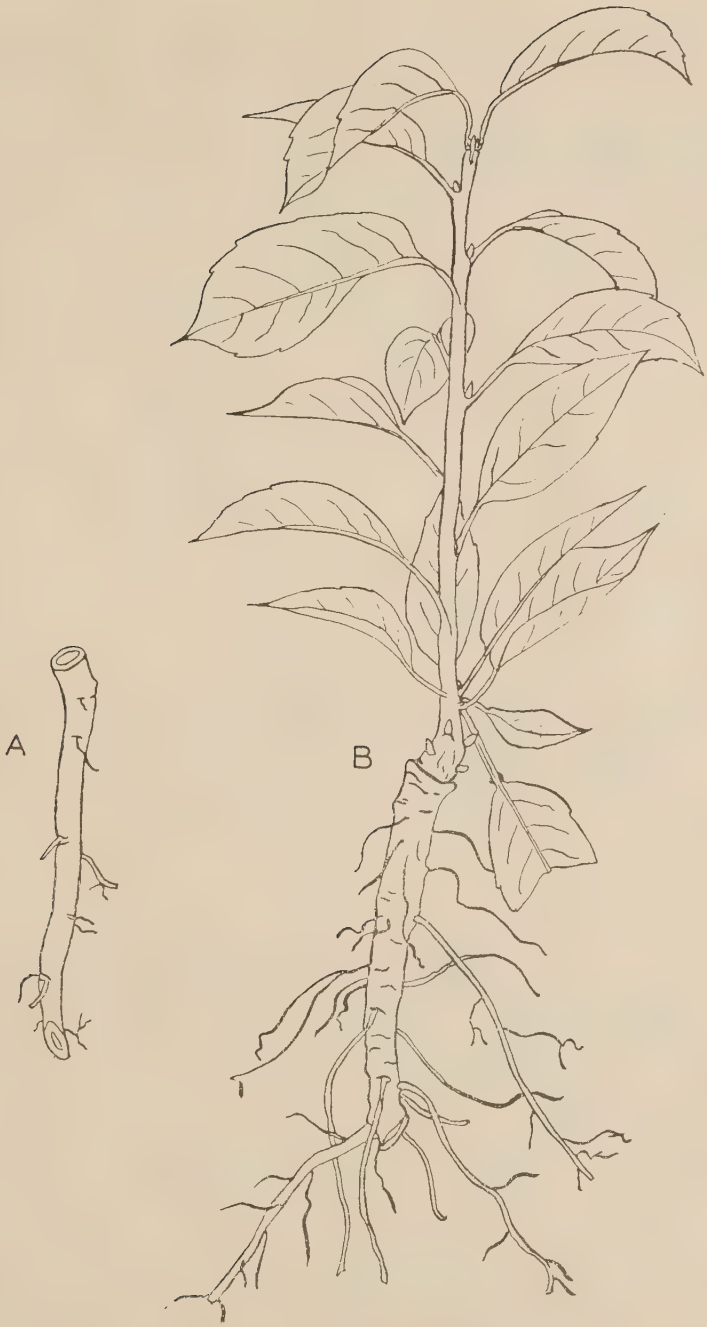


FIG. 4.

Root cutting of sweet cherry (*Prunus avium*).

A. Cutting as planted in early spring.

B. The same the following autumn.

Trees are lifted throughout the dormant season and cuttings are made from the root trimmings as they become available. The most vigorous one-year and two-year root cuttings also supply a certain amount of material at transplanting.

3. HANDLING PRIOR TO PLANTING

Roots $\frac{1}{4}$ in. to $\frac{3}{4}$ in. in diameter are cut into five-inch lengths and stored in moist sandy soil until planted. To make sure of planting the cuttings the right way up the end nearest the crown of the plant is cut square across, whilst the other end is cut slantwise.

4. PLANTING AND SUBSEQUENT TREATMENT

In early spring the cuttings are planted upright two or three inches apart in rows which are spaced for hand cultivation. The upper end of the cutting is just covered with soil. A number of shoots grow from each cutting and, when one to two inches high, they are carefully reduced to one. A piece of cleft bamboo of pencil length is used to expose and separate the shoots to facilitate their removal. Sometimes a further disbudding is necessary later in the season.

The cuttings are lifted the following winter, trimmed and graded. The best are planted for budding and the remainder are cut hard back close to the original root cutting and are replanted as the original cutting. These are generally known as " cut-backs " to distinguish them from ordinary root cuttings.

Success depends largely upon variety and youthfulness of the roots. A return of sixty to eighty per cent. is usual. A typical root cutting and one year plant is shown in Fig. 4.

E. LAYERS—ETIOLATION METHOD

1. VARIETIES

A very wide range of plants will root, at least to some extent, by this method. At East Malling success has been achieved with apples, pears, quinces, plums, cherries, peaches, walnuts, mulberries and various ornamental trees and shrubs of *Pyrus* and *Prunus* species. Elsewhere many tropical and subtropical plants have been successfully propagated by the etiolation method of layering. Considerable skilled attention is needed, consequently the method is used only for subjects which fail to root satisfactorily under the simple treatment of stooling. This layering method is commonly used for the propagation of plum rootstocks and also for cherries, selected pear rootstocks and shy-rooting scion-varieties required for experimental purposes.

2. ESTABLISHMENT

The technique is designed to bring about the etiolation of the base of the young shoots. It also has the effect of distributing growth over a larger number of shoots, thus tending to make them more even in size. The parent rootstocks are planted when dormant at an angle of 45° along the row and are pointed towards the south. The rootstocks are set eighteen to thirty inches apart in the rows which are four feet six inches apart.

Long rootstocks are shortened to prevent loosening by wind and the soil is kept thoroughly cultivated throughout the growing season.

3. TREATMENT IN SECOND YEAR

The parent layers are pegged down in the winter following that in which they were planted. January-February is preferred to the autumn because it decreases the risk of frost lifting the pegs and undoing the work. Any weak lateral growths on the stock are cut back to within half an inch of the main stem. Strong laterals are lightly tipped. Along each row a trench is made about 2 in. deep and wide enough to receive the layer without cramping. The parent layer is pegged down *flat* in this shallow trench so that its tip lies no lower than its base. A little soil is removed near the base to facilitate this operation. Pegs are made from sharpened pieces of wood ten to twelve inches long, having a two-inch wire nail at right angles about an inch from the upper end. Some kinds of wood used green tend to take root in the layer bed, this can be avoided by using dry wood. Small shoots are held down by fifteen-inch lengths of ten-gauge

wire doubled in the form of a letter U (see Fig. 5). Any slender shoots not held by the pegs should be cut back close to the ground.

The entire layer is covered with an inch, or slightly more, of fine soil *before the buds swell*. In the spring the young growths push through the soil with curved growing points. Before these young shoots have uncurled and expanded their leaves, a further inch of soil is placed upon them. No soil is added to areas where shoots have not appeared. This is repeated two or three times during the first few weeks of the growing season. It has the effect of ensuring the etiolation of the first inch or so of the young shoot and it is from this area that roots will appear later in the season, according to variety. Without this etiolation there is little or no rooting.

After the initial earthings, and when the shoots have grown three or four inches above the soil, earth is again added to half the height of the shoot. Further additions are made at intervals of a few weeks, until by the end of July the bases of the shoots are buried six or eight inches.

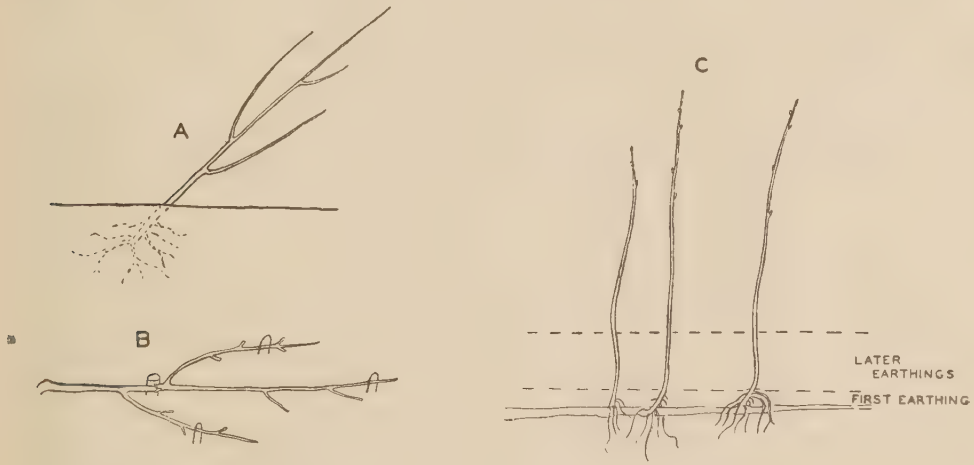


FIG. 5.
The etiolation method of layering.
A. Newly planted parent.
B. Established and pegged down one year after planting.
C. Rooted shoots on the parent layer one year later.

4. TREATMENT IN THIRD AND SUBSEQUENT YEARS

The second winter following planting the first crop of rooted shoots is harvested. The soil is forked away and the one-year-old rooted shoots are removed at their junction with the original layered rootstock. The unrooted shoots are left to be laid and pegged down as before. If all the shoots are rooted, care must be taken to leave at least one shoot every foot or so for layering. After a few years old parts of the layer will die and may be broken out and removed.

At each layering the laid shoots should be kept as flat as possible. All shoots are kept at the same level and no shoot is allowed to lie on top of another. Very strong shoots may be half broken at the base without ill effect.

5. HANDLING THE CROP

At harvesting time the rootstocks are temporarily bundled and carted to the grading shed. Here, on a bench, side growths are removed ; entirely from the lower part and to within half an inch of the stem higher up the stock. If all laterals are entirely removed from much feathered varieties, bud break after planting is seriously delayed. Very long rootstocks are shortened to facilitate handling.

Well rooted stocks of sufficient size are classed as " first grade " and are planted for working or to form further layer beds. Smaller rooted stocks are planted thickly in nursery rows for one season before lining out for working or for propagation.

Crops obtained vary with variety and the skill of the operators. Some of the shy-rooting plum rootstocks such as Brompton and Common Mussel yield, each year, only thirty to forty thousand rooted shoots per acre, little more than half of which are first grade. Other plum rootstocks, such as Myrobalan B, yield over fifty thousand shoots per acre of which 80% are first grade.

F. STOOLS

1. VARIETIES

Many ready rooting subjects are multiplied by stooling and this method is also employed on a large scale by nurserymen for the propagation of bushes and trees. Most apple rootstocks root well on stools as do the quinces used as rootstocks for pear trees.

2. ESTABLISHMENT

The parent rootstocks are planted upright 12 in. apart in rows 3 ft. 6 in. apart. They are planted firmly and cut to within about 18 in. of the ground immediately after planting. Beyond the usual clean cultivation no special treatment is given during the first season.

3. TREATMENT IN SECOND YEAR

The established rootstocks are cut to within an inch of ground level during the winter following that in which they were planted.

A knife is used and care taken to avoid loosening the rootstock in the ground.

The young stools produce from one to five shoots in the first season according to variety. When most of these shoots are 5 in. high the soil, previously made friable by cultivators, is drawn up to and amongst them, by means of a hand hoe, to half the height of the shoots. The space between the rows is cultivated immediately after earthing.

When the shoots have made further growth and are from eight to ten inches in total height, a mould or ridging plough, is drawn between the rows so that ridges of soil are placed on either side of the row of stools. These ridges are some 15 in. apart with the stools between. The bottom of the trench made by the plough is cultivated and the loosened soil is shovelled out and placed close around and between the shoots. A shovelful of soil placed in the middle of a cluster of shoots causes them to bend outwards and this is thought to assist rooting.

A final earthing is made in July, when the shoots are some 18 in. in total height. The soil beneath the bottom of the trench is cultivated once again, whilst the soil is still moist, and is shovelled out and placed amongst the shoots in close contact with them. This final earthing brings the soil six or eight inches above the *base of the shoots* and 12 in. or so above the bottom of the trench between the rows. If rain washes the soil down between the shoots in the middle of the stool, so exposing them to light, it is immediately replaced with more soil from the trench.

4. TREATMENT IN THIRD AND SUBSEQUENT YEARS

In the second winter after planting the soil is forked away and all the shoots are removed by severing them close to the parent stool. The first crop is cut off with a knife to avoid injury to the stool, but later crops may be removed with shears, or be broken off, whichever is the easier.

It is important that established stools should be completely unearthed, otherwise it is not possible to remove the shoots close to the stool and, in a few years, they become so raised by the addition of shoot bases, that it is impracticable to earth sufficiently deeply.

After removing the crop the stools are left exposed until a further crop of shoots arise, when these are earthed as in the previous year. The process is repeated each year. Given good treatment, stools remain productive for upwards of fifteen years according to variety.

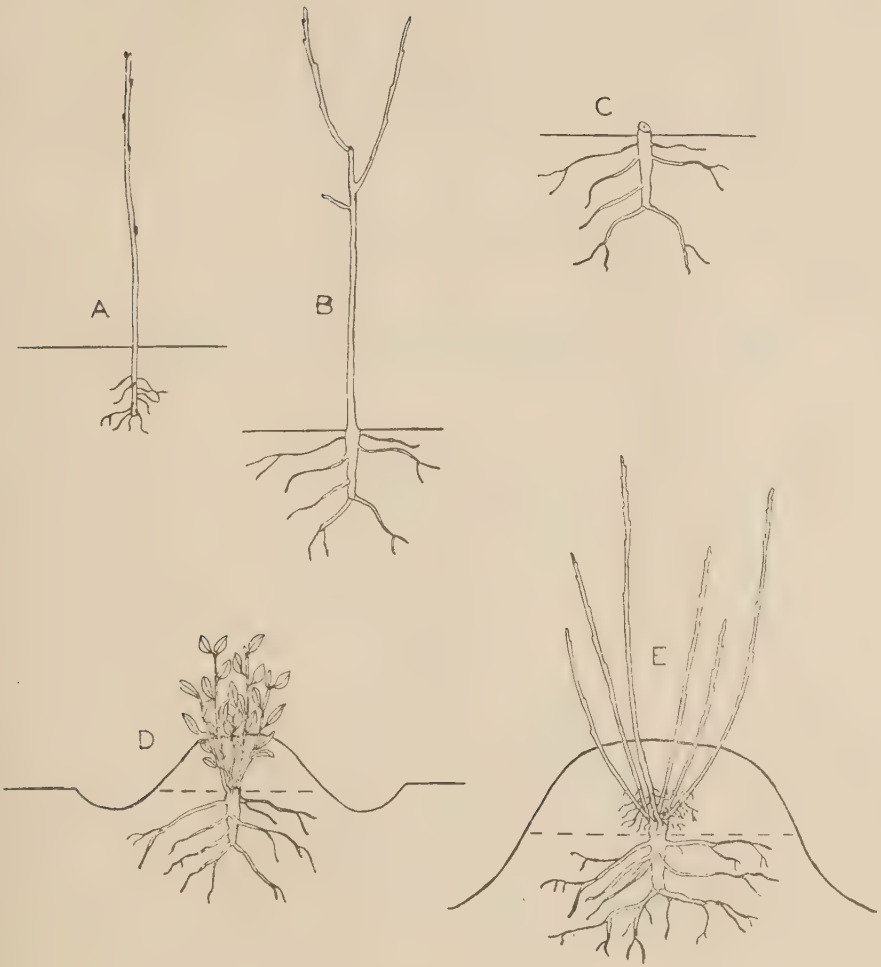


Fig. 6.

The stooling method.

A. Newly-planted parent.

B. Established parent.

C. Cut down one year after planting.

D. Earthed a first time in early summer.

E. Rooted shoots on the stool in winter.

5. HANDLING THE CROP

The crop of shoots is handled as described in the Etiolation method. The removal of all shoots from stools entails the harvesting of some unrooted shoots, especially in bad seasons with certain varieties. These unrooted but blanched shoots may be planted out as cuttings with good success.

Apple rootstocks, such as M. II, produce annual crops of 60,000 shoots per acre of which more than half are first grade. Less prolific sorts, such as M. IX, are not so productive, but the quinces Malling A., B. and C., used as rootstocks for pear, frequently yield annual crops of one hundred thousand per acre, half of which can be classed as first grade. The stooling method is depicted in Fig. 6.

G. TIP LAYERS

1. VARIETIES

The use of this method is confined to blackberries and hybrid-berries of which the loganberry is the chief example. These subjects all readily respond to the treatment, which is an intensification of the natural habit of the plant in propagating itself vegetatively.

2. SOURCE OF SHOOTS

Any of the subjects under discussion left naturally will eventually extend some young vigorous shoots in a curve so that the growing point comes into contact with the soil where it will root, under suitable conditions of moisture, provided it is held still by the growth of weeds or is wedged between stones or crevices in the soil. The propagator endeavours to increase the number of vigorous shoots and provides anchorage for the tip. Increase in number of shoots is brought about by cutting the parent plant back to within a few inches of the ground and the tips, when available, are anchored by inserting them into holes in the ground.

3. MANIPULATION

The technique used at East Malling was perfected by Dr. A. Beryl Beakbane over a period of years.

Healthy young parent plants are set 12 ft. apart, which works out at 300 per acre. The plants are cut to within 9 in. of the ground as soon as planted and thereafter any blossoms which appear are removed each year, to prevent seedlings occurring among the tip plants. The soil is well cultivated and early in July, as soon as the first new shoots are long enough to bend to the ground, a hole is made 6 in. deep with one side vertical and one sloping slightly towards the plant as shown in Fig. 7. The tip is placed in the hole with the cane lying along the sloping side and soil is pressed firmly against it. Placed thus the tip cannot continue to grow in length, but becomes " telescoped " and soon forms an abundant root system and develops a vigorous young vertical shoot.

The bending over of the shoots into the soil causes the growth of vigorous laterals on the bent portion and within a few weeks these are also fit to set in the ground.

Once a parent plant is well established it may produce over twenty first class rooted tips and thus the annual production per acre may exceed six thousand.

4. SUBSEQUENT TREATMENT

In early spring the layered shoots are severed 9 in. or so from the rooted tips, which are lifted carefully and immediately planted, with soil adhering, in nursery rows where they remain one season before being set in their permanent position.

The remains of the layered shoots attached to the parent plant are cut back to 9 in. as in the first year. Economical quantities of shoots are produced annually for upwards of ten years.

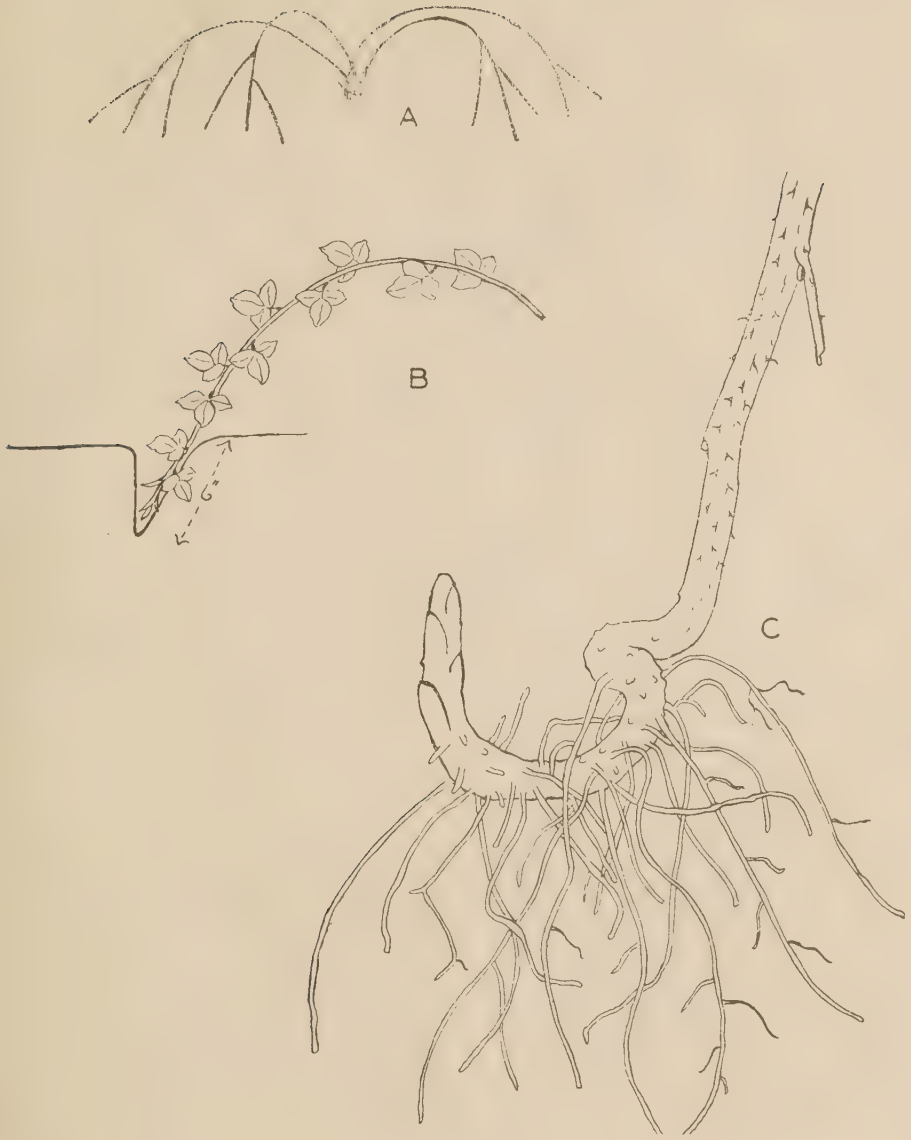


FIG. 7.

Tip layering the loganberry.

A. Diagram of a tip-layered parent plant.

B. Inserting a shoot tip into the soil.

C. A young rooted tip.

THOUGHTS ON FUTURE RESEARCH

In the vegetative multiplication of a plant all the specimens obtained can be reasonably considered as parts of one individual and, under given conditions, will respond similarly to any given treatment. Thus, once beyond the juvenile phase, almost without exception, each separate plant propagated vegetatively will behave identically, provided it remains free of systemic diseases, Smith (1940). Characteristics are established in the original seedling and are supremely important to the propagator. The overriding nature of varietal behaviour is universally recognized but there is, apparently, much more entailed in "variety" than is generally realized.

Individual plants of seedling origin may be almost identical outwardly yet behave very differently in the hands of the propagator. There are numerous examples of this in horticulture where such are recognized as "strains". The selection and propagation of seedlings for use as fruit-tree rootstocks has shown that one group of seedlings comparatively similar in appearance may behave entirely differently in regenerative capacity, disease resistance, compatibility when grafted and influence upon growth and cropping of varieties worked upon them. It is clear, then, that any studies in methods of vegetative propagation must, if they are to eliminate a source of vast error, make use of the progeny of one parent obtained by means of vegetative propagation. Having procured such material, the experimenter may proceed to manipulate it and to modify its environment in order to bring about desired reactions. Such manipulative procedure can be grouped under the heads used earlier.

Investigations on methods of vegetative propagation should cover the whole field from the origin of the parent material used, up to the stage where the new intact plant leaves the nursery. Thus the production of roots on cuttings or layers should not end the investigation but should be regarded as only one step forward. It is important to know more about the further growth and the suitability of the plant for practical use in the nursery. The shape, size and rate of growth of the product are vital practical factors to be kept constantly in mind.

A. CUTTINGS

1. SOURCE OR INTERNAL CONDITION WHEN COLLECTED

The condition of the material used for cuttings is very important and can make all the difference between success and failure. A well selected cutting with rooting potentialities, will root in almost any medium and under a comparatively wide range of temperature and moisture, whereas unsuitable material will fail to root no matter what the medium or the accuracy of climate control. The internal condition of the cutting is of the utmost importance, and until more is known of the factors which combine to modify the nature of the material, advances in other directions will, to a considerable extent, be frustrated.

So far this problem has, in the main, been approached from the ideal angle to discover the best existing material. Thus the age of the parent plant, the condition of the selected shoot, the portion used and time of collection have received considerable attention and much has been learned. The practical application has not always received the attention it deserves and it may well be that studies might reverse their direction with considerable profit. For example, the availability of material in commercial nurseries should be examined. Many plant trimmings, or prunings, are regularly thrown away. Whilst these are often unsuitable for use as cuttings, it may well be that some practical cultural modification of the plant will so change the internal condition and rooting attributes of the prunings that they may prove suitable for further propagation. Thus the rate of multiplication may be increased by the utilization of material now discarded. Existing examples may be seen in the propagation of plum rootstocks by root cuttings obtained in the routine trimming of nursery trees.

Where stock plants are kept solely as a source of cuttings the effect of differential pruning and manuring, or even modifications brought about by the use of hormones and artificially controlled illumination, may result in a favourable response in the cutting.

2. HANDLING PRIOR TO PLANTING

Between taking and planting the material can be concentrated in a very small space. When concentrated various otherwise impractical and costly treatments become practical and worth while. It is at this stage in the operation that chemical treatments are given most conveniently and heat, light and moisture can be modified with comparative ease. Storage under different conditions of heat, light and moisture are apparently of particular importance with hardwood and with root cuttings, and it may well prove economical to place these under closely controlled conditions for a period, whilst internal changes are brought about and followed by good performance when planted.

For example, hardwood cuttings might be collected before they are completely dormant, placed in warm moist conditions to hasten the initiation of internal processes, receive hormone or other chemical treatment and be planted at some definite stage in their development. The study of the effect of light in initiating shoots on the apical ends of root cuttings, whilst under various storage conditions, might prove well worth while and lead to modifications in nursery practice.

3. CONDITIONS AFTER PLANTING

The importance of the medium is well recognized and the main factors, moisture and aeration, brought under control by its use are known to affect rooting. Light also, especially with leafy cuttings, is well known to aid rooting, at least indirectly, by its good effect upon the active processes in the leaf. Unfortunately, in practice, increases in light are accompanied by increases in temperature and though the effect of heat can be modified by humidity control there soon comes a point beyond which, even in a saturated atmosphere, any further increase in light intensity is harmful. The practical propagator is then "between the devil and the deep sea" and he attempts a compromise in high humidity with partial shade. Further knowledge of the effect of light, not directly accompanied by heat, upon the rooting response of leafy cuttings might lead to some improvement in the propagator's technique.

Hardwood cuttings being dormant, or nearly so, when planted, will withstand severe conditions until the spring and early summer, when they become active, and are then more sensitive and sometimes perish under adverse conditions. There have been indications that the planting of woody cuttings before they become dormant, whilst they retain green leaves, is better than planting dormant leafless cuttings. At the earlier stage the plant is more responsive to external stimuli and provided suitable local conditions can be maintained to prevent wilting of the leaves and at the same time retain the comparatively high soil temperature, natural to that season, improved rooting may be obtained. Further work along these lines is needed.

Little is known of the effect of spacing cuttings and its relation to soil moisture and the micro-climate of the cutting bed. Optimum cutting population is a prime factor economically.

Growth substance treatment of cuttings, after planting, in the autumn to retain leaves, and in the spring, to promote rooting, should be considered.

Conditions best suited to bring about rooting are not often those for best growth and, in planning the use of special cutting beds, the desirability of adding nitrogenous and other manures, possibly as a late top dressing, should not be forgotten.

B. LAYERS

The time of covering and the depth of covering layered plants is apparently of much importance, the time in relation to growth and the depth in relation to material used. Little detailed information is available at present. Manipulation of the growth of layered plants, by the application or withholding of manures and by varying the severity of pruning suggest themselves as useful lines of approach. Summer pruning of the shoots on layers by

redistributing growth at critical times, besides affecting root growth, might increase the amount of suitable stem material for cuttings.

External growth control in the form of repeated sprayings with growth substances might lead to the initiation of roots in shy-rooting subjects and to increased root growth in others. Whether this rootgrowth, if any, would occur at the base of mounded shoots or on the parent layer remains to be seen. Should such applications prove materially beneficial, their comparatively low cost would make them acceptable in commerce.

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